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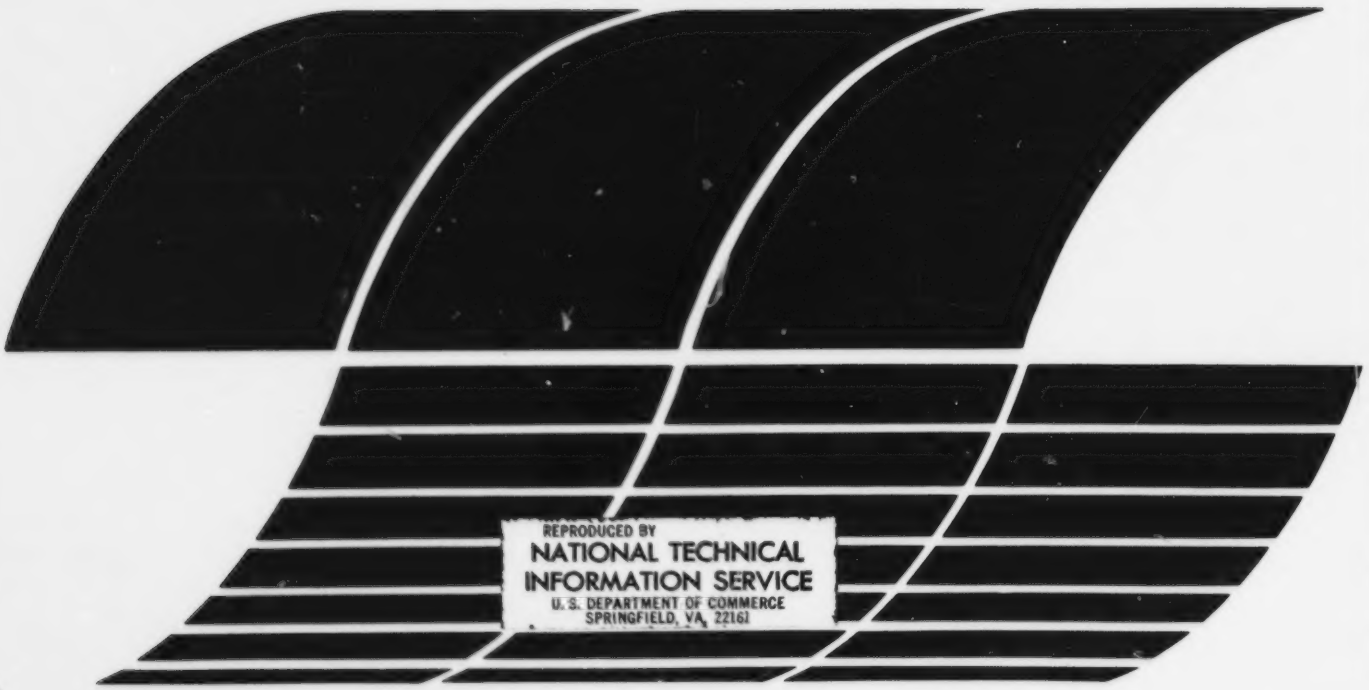

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A mathematical model is developed for the prediction of plume properties such as excess plume temperature, humidity and liquid phase moisture (water droplet), plume trajectory, width, and dilution at the merging locations and the beginning and ending points of the visible part of the plumes. Detailed printout and contour plots of excess temperature and moisture distribution can also be obtained if desired.

Based on comparison with laboratory data this model gives good predictions for the case of dry plumes (no moisture involved). It should be noted that several empirical coefficients are as yet not accurately known. Verification of this model for the wet plume (such as for prototype cooling tower plumes) and the determination of the values for these empirical coefficients to be used in prototype applications must await detailed comparison with field data.

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MATHEMATICAL MODEL FOR MULTIPLE COOLING TOWER PLUMES

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FOREWORD

Effective regulatory and enforcement actions by the Environmental Protection Agency would be virtually impossible without sound scientific data on pollutants and their impact on environmental stability and human health. Responsibility for building this data base has been assigned to EPA's Office of Research and Development and its 15 major field installations, one of which is the Corvallis Environmental Research Laboratory (CERL).

The primary mission of the Corvallis Laboratory is research on the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects and control of pollutants in lake systems; and the development of predictive models on the movement of pollutants in the biosphere.

This report presents a procedure for estimating the nature and extent of dispersions of moist plumes that are emitted from cooling towers. The estimates are useful in assessing environmental impact of these systems.

A. F. Bartsch
Director, CERL

ABSTRACT

A mathematical model is developed resulting in a computer program for the prediction of the behavior of plumes from multiple cooling towers with multiple cells. A general integral method based on the conservation of mass, momentum, energy (heat), and moisture fluxes (before and after a plume merging), were employed in the prediction scheme. The effects of ambient stratifications of temperature, moisture, and wind are incorporated in the model.

An axisymmetric round plume is assumed to be emitted from each individual cell before interference with neighboring plumes. A finite length slot plume in the central part and two half round plumes at both ends of the merged plume were used to approximate the plume after merging. The entrainment and drag functions are calculated based on the modified merged plume shape.

The computer output provides the predicted plume properties such as excess plume temperature, humidity and liquid phase moisture (water droplet), plume trajectory, width, and dilution at the merging locations and the beginning and ending points of the visible part of the plumes. Detailed printout and contour plots of excess temperature and moisture distribution can also be obtained if desired.

Based on comparison with laboratory data this model gives good predictions for the case of dry plumes (no moisture involved). It should be noted that several empirical coefficients are as yet not accurately known. Verification of this model for the wet plume (such as for prototype cooling tower plumes) and the determination of the values for these empirical coefficients to be used in prototype applications must await detailed comparison with field data.

This report was submitted in fulfillment of Grant Number EPA (5) R-803989-01-1 by California Institute of Technology under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from 12/22/75 to 7/31/77, and work was completed as of 7/31/77.

TABLE OF CONTENTS

Chapter		Page
1.	INTRODUCTION	1
2.	THEORETIC MODEL	4
	2.1 Formulation	5
	2.2 Entrainment	13
	2.3 Merging Process	17
3.	COMPUTER PROGRAM	28
4.	RESULTS, COMPARISONS AND DISCUSSIONS	31
5.	CONCLUSIONS AND RECOMMENDATIONS	57
REFERENCES		59
APPENDIX A:	COMPUTER PROGRAM	
APPENDIX B:	EXPLANATIONS OF THE IMPORTANT SYMBOLS IN THE PROGRAM MTP	
APPENDIX C:	LISTING OF PROGRAM	

LIST OF FIGURES

Figure		Page
2.1	Top View of the Coordinate System Associated with the Cooling Tower Configuration	6
2.2	Side View of the Coordinate System Associated with the Cooling Tower Configuration	6
2.3	Merged Plume Shape	19
2.4	Definition Sketch	20 21
2.5	Modified Merged Plume Shape	24
2.6	Correction of Δy for the Merged Plume	26
3.1	Flow Chart of the Computer Program	30
4.1	Excess Temperature Distribution for the Case of 4 Towers in Linear Array and 0° to Wind Direction	32
4.2	Excess Humidity Distribution for the Case of 4 Towers in Linear Array and 0° to Wind Direction	33
4.3	Excess Liquid Phase Moisture Distribution for the Case of 4 Towers in Linear Array and 0° to Wind Direction	34
4.4	Excess Temperature Distribution for the Case of 4 Towers in Linear Array and 90° to Wind Direction	35
4.5	Excess Humidity Distribution for the Case of 4 Towers in Linear Array and 90° to Wind Direction	36
4.6	Excess Liquid Phase Moisture Distribution for the Case of 4 Towers in Linear Array and 90° to Wind Direction	37
4.7	Excess Temperature Distribution for the Case of 4 Towers in Linear Array and 135° to Wind Direction	38
4.8	Excess Humidity Distribution for the Case of 4 Towers in Linear Array and 135° to Wind Direction	39
4.9	Excess Liquid Phase Distribution for the Case of 4 Towers in Linear Array and 135° to Wind Direction	40

LIST OF FIGURES (Continued)

Figure		Page
4.10	Excess Temperature Distribution for the Case of 5 Towers in Round Array	41
4.11	Excess Humidity Distribution for the Case of 5 Towers in Round Array	42
4.12	Excess Liquid Phase Moisture Distribution for the Case of 5 Towers in Round Array	43
4.13	Comparisons of Plume Trajectory, Width and Dilution Between the Present Theory and Fan's (1967) Experiments for $F = 20$ and $K = 8$	45
4.14	Comparisons of Plume Trajectory, Width and Dilution Between the Present Theory and Fan's (1967) Experiments for $F = 40$ and $K = 8$	46
4.15	Comparisons of Plume Trajectory, Width and Dilution Between the Present Theory and Fan's (1967) Experiments for $F = 80$ and $K = 16$	47
4.16	Comparisons of Plume Excess Temperature Between the Present Theory and Chan et al.'s (1974) Experiments for $F = 4$ and $K = 1.02$	48
4.17	Comparisons of Plume Trajectories Between the Present Theory and TVA (1968, TVA-11, single tower) Field Data in a Stable Atmospheric Condition ($\partial\theta/\partial z = 0.59°K/100$ m)	50
4.18	Comparisons of Plume Trajectories Between the Present Theory and TVA (1968, TVA-14, two towers) Field Data in an Atmosphere with an Inversion ($\partial\theta/\partial z = 1.42°K/100$ m)	51

LIST OF TABLES

Table		Page
4.1	Input Data Cards for Example Cases (Different Wind Directions to a Line Array (3 cases) and Round Array (one case) of Towers)	52
4.2	Input Data Cards for Three Cases of Fan's (1967) Experiments with F = 20, K = 8; F = 40, K = 8; and F = 80, K = 16	53
4.3	Input Data Cards for Chan et al.'s (1974) Experiment with F = 4, K = 1.02	54
4.4	Input Data Cards for TVA (1968, TVA-11, single tower) Field Data in a Stable Atmospheric Condition ($\partial\theta/\partial z = 0.59°K/100$ m)	55
4.5	Input Data Cards for TVA (1968, TVA-14, two towers) Field Data in an Atmosphere with an Inversion ($\partial\theta/\partial z = 1.42°K/100$ m)	56

LIST OF SYMBOLS

a_1	Entrainment coefficient associated with jet type entrainment
a_2	Entrainment coefficient associated with the effect of buoyancy
a_3	Entrainment coefficient associated with thermal type entrainment
a_4	Entrainment coefficient associated with ambient turbulence
a	Finite length of the slot plume in the central part of the merged plume
A	Finite length of the slot plume in the central part of the modified merged plume
b	Plume radius
b_{r1}, b_{r2}	Plume radii at the ends of the merged plume
b_s	Plume width of the slot plume in the central part of the merged plume
B1,B2	Plume radii at the ends of the modified merged plume
BXZ	Plume half height of the cross-section normal to s-axis
BY	Plume half width
C	Tracer concentration
C_d	Drag coefficient
C_{pa}	Specific heat at constant pressure
e_s	Saturation vapor pressure
E	Volume rate of entrainment
E_{1r}	Volume rate of entrainment associated with the effects of momentum and buoyancy for a round plume
E_{1s}	Volume rate of entrainment associated with jet type entrainment for slot plume
E_2	Volume rate of entrainment associated with thermal type entrainment

LIST OF SYMBOLS (Continued)

E_3	Volume rate of entrainment associated with ambient turbulence
F	Sum of excess vapor and liquid phase moisture fluxes (H+W)
F^2	Densimetric Froude number ($m^{5/2}/\mu^2\beta$)
Fr_L	Local densimetric Froude number ($U_p^2/[(\rho_a-\rho_p)bg/\rho_o]$)
Fr_{LC}	Critical local densimetric Froude number
g	Acceleration of gravity
G	$T - L_v W/C_{pa}$
H	Excess vapor phase (humidity) moisture flux
HT	Total height of the merged plume
L_v	Latent heat of evaporation or condensation
m	Kinematic momentum flux ($\int_A u_p^2 dA$)
M	Excess kinematic momentum flux
p_d	Dry air absolute pressure
p_t	Total absolute pressure ($p_d + e_s$)
P	Plume periphery
q	Specific vapor phase moisture (humidity)
Q	Plume volume flux
s	Plume trajectory
t	Temperature
t_s	Steam point temperature
T	Excess temperature flux
U	Velocity
U_a'	Measure of ambient turbulent fluctuation
U_{r1}, U_{r2}	Plume velocities at both ends of merged plumes

LIST OF SYMBOLS (Continued)

U_s	Plume velocity at central part of merged plume
W	Excess liquid phase moisture flux
W_d	Plume width
WD	Total width of the merged plume
x	x-coordinate (parallel to wind direction)
y	y-coordinate (normal to x-axis)
z	z-coordinate (vertical coordinate)
α_j	Entrainment coefficient for pure jet ($F_1 \to \infty$)
α_p	Entrainment coefficient for pure plume
β	Buoyancy flux ($\int_A g U_p (\rho_a - \rho_p)/\rho_a dA$)
Γ	Adiabatic lapse rate
θ	Angle between the tangent of s and x-axis
ρ	Density
σ	Liquid phase moisture
ϕ	Angle between the centerline of the (inclined) plume cross-section and the horizontal line parallel to y-axis
μ	Volume flux ($\int_A U_p dA$)
$(\ )_a$	in ambient
$(\ )_o$	at tower exit
$(\ )_p$	in plume

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CHAPTER 1

INTRODUCTION

The use of multiple cooling towers is a common means of disposal of waste heat from large power plants. A better understanding of the behavior and interaction of plumes from multiple towers would be useful not only to cooling tower design and operation, but also in the assessment of their environmental impact. Due to the relatively close proximity of neighboring tower exits, the individual plumes from multiple cooling towers rapidly interfere with one another, thus changing the overall plume shape and its mixing characteristics. In addition, the ambient stability (temperature profile), humidity, wind velocity and wind direction to the tower array also influence the plume behavior. In this report a mathematical model resulting in a computer program is developed which will provide the framework to allow reasonable predictions to be made of the characteristics of plumes from multiple cooling towers under various ambient conditions.

Throughout this report, no distinction will be made between a plume and a jet. Neither will the distinction be made between the multiple plumes from the several cells of a tower and the multiple plumes from several individual towers.

The plume from a cooling tower is a buoyant jet which has been studied in the past by numerous investigators, such as Morton, et al. (1956), Morton (1957), Slawson and Csanady (1967,1971), Koh and Brooks (1975). Several existing single tower plume models, including dry and wet plumes, were developed by Briggs (1969), Hoult et al. (1969), Abraham (1970), Fox (1970), Csanady (1971), Wigley and Slawson (1971, 1972),

Hirst (1971), Hanna (1972), Weil (1974), Wigley (1975a,b), and Schatzmann (1977).

A model for multiple plumes was first developed by Koh and Fan (1970) in analysing the analogous problem of disposal of waste heat into the ocean by multiple port diffusers. The integral method was used and the individual round buoyant jets were approximated by a two-dimensional slot jet after interference. A transition region during merging was considered. Although a discontinuous centerline temperature resulted at the point of merging, the overall predictions of the plume properties were quite satisfactory. Jirka and Harleman (1974) approached the multiple port diffuser problem by replacing it with an equivalent slot jet having the same mass and momentum fluxes as the multi-port discharge. As expected this method generally over-estimates dilution except for those instances when the plumes are very close to each other initially. Briggs (1974) added an enhancement factor to his single tower equation for plume rise by considering the effects of number of towers and tower spacing. Meyer et al. (1974) modified Briggs' equation and used a "peak factor" to develop a model which can give a fairly good prediction of visible plume length. However, the prediction of the plume trajectory is less accurate. Davis (1975) developed a mathematical model for calculating plume rise and dilution from multiple cell mechanical draft cooling towers with the wind normal to the tower array. The entrainment function used includes the effects of plume interference and the changing entrainment surfaces during merging. The model also provides calculation techniques for various modes of plume development. The plume properties remain continuous when the calculations proceed

smoothly from one zone to another. The values of the coefficients in his entrainment function still need to be determined from suitable laboratory and field experiments.

Data from multiple towers are very scarce. Chan et al. (1974) made laboratory simulations of plumes from multiple towers using water as the fluid medium. Two sets of normalized excess temperature distributions were presented. These are useful for model comparisons. The studies by Carpenter et al. (1968) and Slawson et al. (1975) at TVA gave field data on plume trajectory and some plume properties. More complete data including plume trajectory, width, dilution, and ambient conditions (i.e. temperature, humidity and wind velocity profiles, wind direction to tower array, tower configuration, etc.) however are required for proper verification.

The model developed in this report is based on a general integral method applied to the conservation equations for mass, momentum, energy, and moisture fluxes. An axisymmetric round plume is assumed initially for each tower exit. As the plumes merge, combinations of round and slot plumes are employed to simulate the shape of the resulting merged plumes. The merging criteria, merging processes, changes of plume shape and entrainment functions are a part of the model and are discussed in Chapter 2. Some results of model predictions and comparisons with laboratory and field data are presented and discussed in Chapter 4. A computer program has been written to perform the calculations and is included in Chapter 3 and Appendices A and C.

CHAPTER 2

THEORETICAL MODEL

The present mathemtical model is developed for the prediction of plume properties from multiple cooling towers. These include plume temperature, moisture (vapor and liquid phases), excess temperature, excess moisture, velocity, width, dilution, trajectory and visible plume length. For ease of application to practical situations, this model is capable of handling rather arbitrary vertical profiles of ambient temperature, humidity, and velocity; arbitrary but steady wind direction to the tower array; and randomly arranged tower configurations.

The assumptions made in developing this model are as follows:

1. The flow is fully turbulent. Molecular transport can be neglected in comparison with turbulent transport so that there is no Reynolds number dependence.

2. Longitudinal turbulent transport is small compared with longitudinal advective transport.

3. Pressure is hydrostatic throughout the flow field.

4. The cross-plume profiles are similar for plume velocity, temperature, density, humidity and liquid phase moisture.

5. The Boussinesq assumption is valid. This implies that the variations of fluid density throughout the flow field are small compared with the reference density chosen. The variations in density are only considered in the buoyancy term.

Using these assumptions, a general integral model for multiple cooling tower plumes based on the conservation of mass, momentum, energy and moisture fluxes along the plume trajectory is developed. By providing

the ambient conditions and the empirical equations for entrainment and drag, the conservation equations are integrated stepwise for the center line properties along the plume trajectory. Before interference the plumes are assumed to be individual, axisymmetric, round buoyant jets. During the merging process, a combination of a finite slot jet in the central part and two half round jets at both ends is assumed to be the cross-sectional shape of the merged plume as an approximation but only for the calculation of entrainment and drag. Finally, the completely merged plume gradually tends to become round in cross section again, whereupon the individual axisymmetric analysis is reapplied. The formulations of the basic plume conservation equations, entrainment function, merging criterion and merging process are presented in the following sections.

2.1 Formulation

The coordinate system chosen with a typical cooling tower configuration is shown in Figures 2.1 and 2.2. The x-axis is parallel to the steady ambient wind direction. s is the coordinate along the plume path and θ is the angle between the tangent to s and the x-axis. The individual plumes from the cooling tower cells are presumed to be discharged vertically into a stratified atmosphere, and bent over due to the effect of ambient wind. The plume properties are defined as velocity U, density ρ, temperature t, specific humidity q, and liquid phase moisture σ. Here, the specific humidity (vapor phase moisture) q and liquid phase moisture σ are defined as the ratio of mass of vapor (or liquid) phase moisture to the total mass of the mixture in a unit volume. The subscripts o, p, and a are used for the values at tower

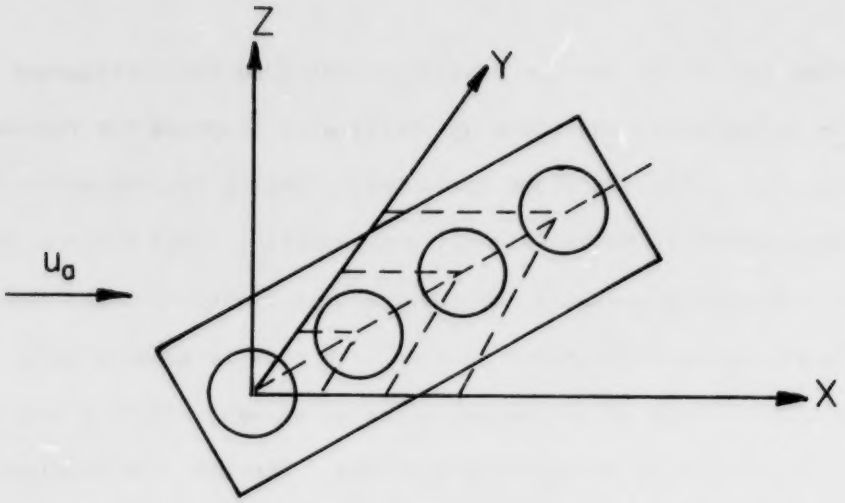

Figure 2.1 Top View of the Coordinate System Associated with the Cooling Tower Configuration

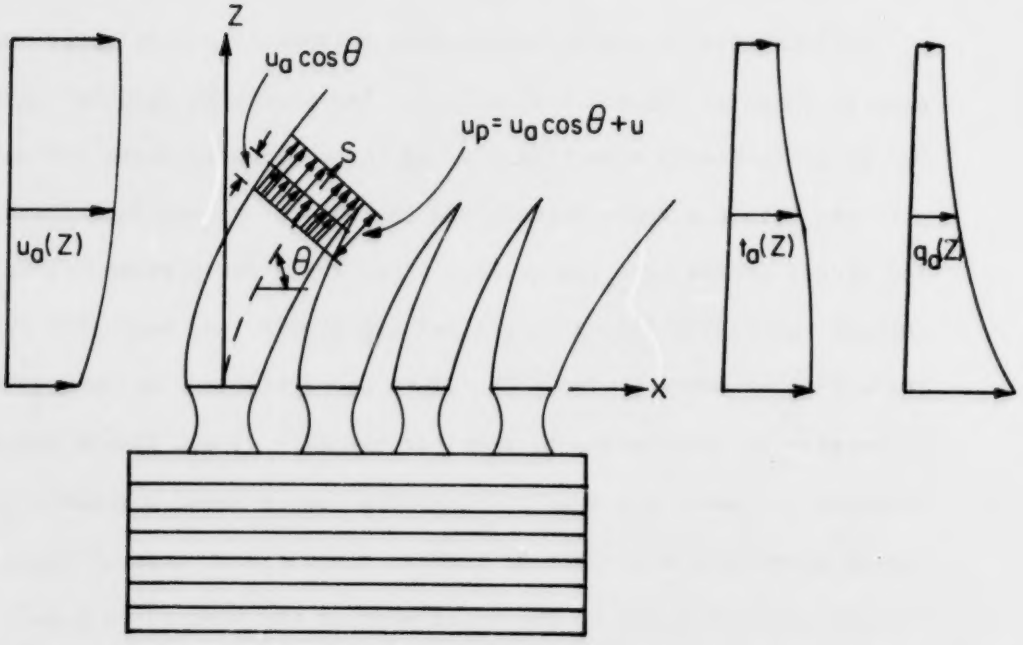

Figure 2.2 Side View of the Coordinate System Associated with the Cooling Tower Configuration

exit, in the plume, and in the ambient atmosphere, respectively. The plume volume flux Q, kinematic momentum flux M, temperature deficiency flux T, vapor phase moisture (or humidity) deficiency flux H, and liquid phase moisture deficiency flux W are defined as follows:

$$Q = \int_A U_p \, dA \tag{2.1}$$

$$M = \int_A U_p^2 \, dA \tag{2.2}$$

$$T = \int_A (t_p - t_a) \, U_p \, dA \tag{2.3}$$

$$H = \int_A (q_p - q_a) \, U_p \, dA \tag{2.4}$$

$$W = \int_A (\sigma_p - \sigma_a) . U_p \, dA \tag{2.5}$$

Any 'rainout' of liquid droplets in the ambient atmosphere will be neglected so that σ_a is equal to zero.

The conservation of mass equation is:

$$\frac{d}{ds} \{ \int_A \rho_p \, U_p \, dA \} = \rho_a E \tag{2.6}$$

where E is the volume rate of entrainment of ambient fluid. The function used for E is an empirical expression including the effects of plume geometry, local mean velocity, buoyancy and ambient turbulence. The detailed form of E is presented in Section 2.2.

The conservation equation for horizontal momentum flux is:

$$\frac{d}{ds} \{ \int_A \rho_p \, U_p^2 \, dA \cdot \cos\theta \} = \rho_a U_a E + \frac{1}{2} \rho_a U_a^2 \sin^2\theta \, C_d \, W_d |\sin\theta| \tag{2.7}$$

where the first term on the right hand side of equation (2.7) is due to the momentum of the entrained ambient fluid and the second term is due to the horizontal drag force (Fan, 1967) on the plume; C_d is a drag coefficient to be determined empirically and W_d is the width of the plume; the absolute value of $\sin\theta$ is used in order to account for both the ascending and descending parts of the plume.

The conservation equation for vertical momentum flux is:

$$\frac{d}{ds}\{\int_A \rho_p U_p^2 \, dA \cdot \sin\theta\} =$$

$$g\int_A (\rho_a - \rho_p)\, dA - g\int_A \rho_p \sigma_p dA \mp \frac{1}{2}\rho_a U_a^2 \cdot \sin^2\theta \, C_d W_d \cos\theta \qquad (2.8)$$

where the first term on the right hand side of equation (2.8) is the buoyancy force due to the density difference between the plume and ambient fluid; the second term is the effect of the weight of liquid droplets suspended in the plume; the third term is the vertical drag force on the plume with the negative and positive signs corresponding to $0 \leq \theta \leq \pi/2$ and $-\pi/2 \leq \theta < 0$, respectively.

Koh and Fan (1970) have shown that the governing equation for the flux of a tracer quantity C is as follows:

$$\frac{d}{ds}\int_A (C_p - C_a) U_p \, dA = -\frac{dC_a}{ds}\int_A U_p \, dA \qquad (2.9)$$

where C_p and C_a are the tracer concentrations in the plume and the ambient, respectively. Now considering the temperature flux and also taking into account the effects of atmospheric adiabatic lapse rate Γ

and the liberation of latent heat due to condensation of water vapor inside the plume (Csanady, 1971), the conservation equation for energy (or heat) flux is derived as follows:

$$\frac{d}{ds}\int_A (t_p - t_a)\, U_p\, dA = -\left(\frac{d\, T_a}{dz} + \Gamma\right) \sin\theta \int_A U_p\, dA + \frac{d}{ds}\int_A \frac{L_v}{C_{pa}}\, \sigma_p\, U_p\, dA \tag{2.10}$$

where L_v is the latent heat of evaporation (or condensation) i.e., $L_v(t) = [597.31 - 0.57x(t°C)] \times 4.1868\ Jg^{-1}$ for $t \geq 0°C$ and $L_v = [677 + 0.622 \times (t°C)] \times 4.1868$ for $t<0°C$, and C_{pa} is the specific heat of air at constant pressure.

The conservation equation for (vapor and liquid phase) moisture flux is:

$$\frac{d}{ds}\int_A (q_p - q_a)\, U_p\, dA + \frac{d}{ds}\int_A \sigma_p\, U_p\, dA = -\frac{dq_a}{dz} \sin\theta \int_A U_p\, dA \tag{2.11}$$

We assume a top-hat distribution of plume properties across the plume. Therefore, U_p, T_p, ρ_p, q_p, and σ_p are constants inside the plume. In particular, U_p is defined as follows:

$$U_p = U_a \cos\theta + U \tag{2.12}$$

where U is the 'net' plume velocity relative to the ambient wind.

Applying the relationship between temperature and density for a constant pressure process (pressure variations in the plume cross section is neglected) we can write:

$$\frac{\rho_a}{\rho_p} = \frac{t_p}{t_a} \; ; \text{ and } \frac{\rho_a - \rho_p}{\rho_p} = \frac{t_p - t_a}{t_a} \tag{2.13}$$

The conservation equations may now be rewritten as:

$$\frac{dQ}{dS} = \frac{t_p}{t_a} E \tag{2.14}$$

$$\frac{d}{ds}\{M \cos\theta\} = \frac{t_p}{t_a}\{U_a E + 0.5 U_a^2 \sin^2\theta C_d W_d |\sin\theta|\} \tag{2.15}$$

$$\frac{d}{ds}\{M \sin\theta\} = g\left\{\frac{t_p - t_a}{t_a} - \sigma_p\right\} \int_A dA \mp \frac{t_p}{t_a} 0.5 U_a^2 \sin^2\theta C_d W_d \cos\theta \tag{2.16}$$

$$\frac{d}{ds}\{T - \frac{L_v}{C_{pa}} W\} = -\left(\frac{d\, t_a}{dz} + \Gamma\right) \cdot \sin\theta \cdot Q \tag{2.17}$$

$$\frac{d}{ds}\{H + W\} = -\frac{dq_a}{dz} \cdot \sin\theta \cdot Q \tag{2.18}$$

In addition, the equations for the geometrical relations yield

$$\frac{dx}{ds} = \cos\theta \tag{2.19}$$

$$\frac{dz}{ds} = \sin\theta \tag{2.20}$$

Since U_p, t_p, σ_p and W_d can be written in terms of M, Q, T and W (Koh and Fan, 1970); for instance, $U_p = 2M/Q$ for round plume, the system of equations (2.14) to (2.20) constitute seven ordinary differential equations for the eight unknowns, Q, M, θ, T, H, W, x and z as functions of s. For closure, one more equation is needed. This extra condition is:

$$\sigma_p = 0 \qquad \text{for } q_p < q_{sp} \text{ (dry plume)}$$

$$q_p = q_{sp}(t_p) \qquad \text{for } q_p \geq q_{sp} \text{ (wet plume)} \tag{2.21}$$

where q_{sp} is the plume saturation specific humidity.

Equation (2.21) implies that when the plume is unsaturated, no liquid phase moisture due to condensation need be considered and when the plume is saturated, the plume humidity is equal to the plume saturation specific humidity. To calculate the saturated specific humidity, thermodynamic equilibrium between liquid and vapor is assumed. The Clausius-Clapeyron equation (or tabulated values) can then be used to calculate the saturated humidity. The equation used in the model to calculate the saturated specific humidity q_s is (Linsley et al., 1975):

$$q_s(t,p) = \frac{0.622 e_s(t)}{P_t - 0.378\ e_s(t)} = \frac{0.622\ e_s(t)}{P_d(z) + e_s(t) - 0.378\ e_s(t)} \tag{2.22}$$

where t and p are absolute temperature and pressure, respectively; P_t is the total pressure which is the sum of the dry air pressure $P_d(z)$ and the saturated vapor pressure $e_s(t)$.

Since the variation of pressure is small (for instance, ΔP = 1% of P corresponding to $\Delta z \simeq$ 100M), the absolute pressure at sea level (i.e., P_d = 1013.25 mb) is used in equation (2.22), which becomes:

$$q_s(t) = \frac{0.622\ e_s(t)}{1013.25 + 0.622\ e_s(t)} \tag{2.23}$$

An approximate expression of $e_s(t)$ was developed by Richards (1971) as

$$e_s(t)=1013.25 \times \exp(13.3185\ t_v - 1.9760\ t_v^2 - 0.6445\ t_v^3 - 0.1299\ t_v^4)$$

where

$$t_v = 1 - \frac{t_s}{t}$$

and t_s is the steam point temperature (°K). The result from this equation is very accurate (to within 0.1%) over the wide range of temperature -50°C to 140°C (Wigley, 1974). Within the range 0° to 100°C it is accurate to within the limits of accuracy of the accepted Goff-Gratch formula. In this study t_s is equal to 373.16°K. Because both q_s and t are unknown in the governing equations, the implicit form of equation (2.23) would require an iteration scheme in the calculation. In the model, the Newton method was adopted for this iteration.

With the additional equation (2.23) and the Newton iteration method, the system of equations (2.14) to (2.21) may now be solved given the initial values of the unknowns at tower exit (or s=o). The initial values are as follows;

$$Q_o = \int_A U_p\, dA = \frac{\pi}{4} D_o^2\, U_o$$

$$\theta_o = 90°$$

$$M_o \cos\theta_o = 0$$

$$M_o \sin\theta_o = \int_A U_p^2\, dA = \frac{\pi}{4} D_o^2\, U_o^2 = Q_o\, U_o$$

$$G_o = T_o - \frac{L_v}{C_{pa}} W_o = \frac{\pi}{4} D_o^2\, U_o\, (t_o - t_{ao} - \frac{L_v}{C_{pa}} \sigma_o) \qquad (2.24)$$

$$= Q_o (t_o - t_{ao} - \frac{L_v}{C_{pa}} \sigma_o)$$

$$F_o = H_o + W_o = \frac{\pi}{4} D_o^2\, U_o\, (q_o - q_{ao} + \sigma_o)$$

$$= Q_o\, (q_o - q_{ao} + \sigma_o)$$

$$x_o = 0$$

$$z_o = 0$$

where the subscripts o and ao are associated with the values at tower exit (or initial values) and the ambient at the same level, and $L_v(t) = [597.31 - 0.57 \times t_o(°C)] \times 4.1868\ Jg^{-1}$, and $C_{pa} = 1.005\ Jg^{-1}{}^{\circ}K^{-1}$.

2.2 Entrainment

The entrainment of ambient fluid into the plume is a function of plume geometry, local mean velocity, buoyancy, and ambient turbulence. The entrainment function first proposed by Morton et al. (1956) is:

$$E_{1r} = \alpha\ 2\pi b\ U_p \tag{2.25}$$

where α is entrainment coefficient determined from experiments; b is the round jet radius; and U_p is the jet centerline velocity.

Based on the integral conservation equations of mass, momentum, energy, and mechanical energy, and assuming similar profiles, Fox (1970) and Hirst (1971) derived an entrainment function for round jets which includes the effect of buoyancy to the entrainment. It reads as follows:

$$E_{1r} = \left(a_1 + \frac{a_2}{Fr_L} \sin\theta\right) 2\pi b\ U_p \tag{2.26}$$

where a_1 and a_2 are entrainment coefficients, and Fr_L is the local densimetric Froude number defined as $Fr_L = U_p{}^2/[(\rho_a - \rho_p)\ b\ g/\rho_o] = U_p{}^2/[(t_p - t_a)\ t_o bg/t_p\ t_a]$, and g is gravitational acceleration. Based on experimental results, a_1 was determined to be 0.057 for pure round jet with Gaussian profile distribution (i.e., $Fr_L \to \infty$). Hirst (1971) suggested the value of $a_2 = 0.97$. This appears to be too large when his results are compared with experiments. A better estimate of the value of

a_2 can be made from the work of List and Imberger (1973), who, based on dimensional analysis and experimental data, derived a similar expression for E_{1r} for round jets (Koh and Brooks, 1975)

$$E_{1r} = (0.057 + \frac{0.083}{F^2})\ 2\pi b\ U_p \qquad (2.27)$$

where $F^2 = m^{5/2}/\mu^2\beta$ with m being the kinematic momentum flux $= \int_A U_p^2\ dA$, μ the volume flux $= \int_A U_p\ dA$, and β the buoyancy flux $= \int_A gU_p \frac{\rho_a - \rho_p}{\rho_a}\ dA$.

Comparing equations (2.26) and (2.27) in a quiescent ambient (i.e. $\sin\theta = 1$) and calculating F^2 by using the Gaussian similarity profiles for U_p and ρ_p, one finds $a_2 = 0.083\ Fr_L/F^2 = 0.4775$. Hence equation (2.26) becomes

$$E_{1r} = (0.057 + \frac{0.4775}{Fr_L}\ \sin\theta)\ 2\pi b\ U_p \qquad (2.28)$$

The entrainment coefficient α in equation (2.25) has the extreme values for pure jet (i.e., $Fr_L \to \infty$) $\alpha_j = 0.057$ and pure plume (i.e., $Fr_L \to 0$) $\alpha_p = 0.082$ in a quiescent ambient. A critical value of Fr_L may be determined from

$$0.082 = 0.057 + \frac{0.4775}{Fr_{LC}}$$

which gives

$$Fr_{LC} = 19.1$$

For Gaussian similarity profiles of plume properties it will be assumed that

$$\begin{aligned} E_{1r} &= (0.057 + \frac{0.4775}{Fr_L}\ \sin\theta)\ 2\pi b\ U_p \quad \text{for } Fr_L > 19.1 \\ &= 0.082 \cdot 2\pi b\ U_p \qquad\qquad\quad \text{for } Fr_L \leq 19.1 \end{aligned} \qquad (2.29)$$

which implies that $Fr_L = 19.1$ was considered a small number below which the entrainment of a buoyant jet is similar to that of a pure plume.

Experimental results for two-dimensional slot jet are not sufficiently comprehensive to obtain a similar entrainment expression [i.e., equation (2.29)] (Koh and Brooks, 1975). Therefore, based on the experimentally determined entrainment coefficient, the following form will be used for the slot jet with Gaussian profile distribution, viz.,

$$E_{1s} = 0.14 \cdot 2A \cdot U_p \tag{2.30}$$

where A is the length of the slot jet.

The entrainment functions embodied in equations (2.29) and (2.30) are based on Gaussian profiles of plume properties. In this study, top-hat similarity profiles are assumed. The difference in the resulting entrainment functions [equations (2.29) and (2.30)] due to this is a factor of $\sqrt{2}$. Therefore, equations (2.29) and (2.30) can be rewritten as follows:

$$\begin{aligned} E_{1r} &= \left(0.0806 + \frac{0.6753}{Fr_L} \sin\theta\right) 2\pi b\, U_p \quad \text{for } Fr_L > 19.1 \\ &= 0.1160 \quad 2\pi b\, U_p \quad \text{for } Fr_L \leq 19.1 \end{aligned} \tag{2.31}$$

$$E_{1s} = 0.198 \cdot 2AU_p \tag{2.32}$$

As the plume bends over towards the direction of the ambient wind, the plume velocity is about equal to the wind velocity. Then the entrainment should be nearly as if the plume were a two-dimensional thermal in a stagnant atmosphere. This entrainment is proportional to the jet periphery and the velocity of the thermal. Abraham (1970) proposed the

following form

$$E_2 = a_3 \, P \, U_a \sin\theta \cos\theta \qquad (2.33)$$

where P is the jet periphery, $\cos\theta$ is arbitrarily chosen to diminish the thermal type of entrainment closed to the initial stage of the vertical jet, and a_3 is the entrainment coefficient for a line thermal. For large Reynolds number, the experimentally determined value of a_3 is 0.5 (Richards, 1963). But a better value suggested by Koh and Chang (1973) from their plume measurements and numerical model is 0.3536, which will be used in this present model. Thus

$$E_2 = 0.3536 \, P \, U_a \sin\theta \cos\theta \qquad (2.34)$$

Another type of entrainment is associated with ambient turbulence, and expressed as

$$E_3 = a_4 \, P \, U_a' \qquad (2.35)$$

where a_4 and U_a' are the entrainment coefficient and a measure of turbulent velocity fluctuations. Based on dimensional analysis, Briggs (1969) found that U_a' is associated with eddy energy dissipation in the inertial subrange and gave an estimate of $a_4 = 1$. In practice, the root-mean-square value of the ambient wind velocity fluctuation may be used to approximate U_a', which is equal to a few percent of the mean wind velocity under normal atmospheric conditions.

Finally, we may combine equations (2.31), (2.32), (2.34) and (2.35) to construct a complete entrainment function as

$$E = P \, \{\alpha|U| + 0.3536 \, U_a |\sin\theta| \cos\theta + 1.0 \, U_a'\} \qquad (2.36)$$

where for a round jet,

$$P = 2\pi b$$

$$\alpha = 0.0806 + \frac{0.6753}{Fr_L}|\sin\theta| \quad \text{for } Fr_L > 19.1$$

$$= 0.1160 \quad \text{for } Fr_L \leq 19.1$$

and for a slot jet,

$$P = 2A$$

$$\alpha = 0.198$$

Here U is the net velocity in the plume relative to the ambient velocity; the absolute value is used here to account for both the ascending and descending parts of the plume.

In the literature on buoyant jets, various investigators employing the integral approach have devised differing entrainment functions. A recent survey for the round jet can be found in Wright (1977). The entrainment function expressed in equation (2.36) and incorporated in the present model is but one possible expression. Should a different form be shown to be superior in the future, the model can readily be modified.

2.3 Merging Process

The individual plumes from the multiple cells of a cooling tower typically merge within a relatively short distance from the exits. Before the plumes merge, equations for individual round buoyant jets are applied in this model to calculate the plume behavior. When several individual plumes are merged, the resulting plume cross-section is no longer round, but rather tends to be elliptical in shape. In this model,

this merged plume is approximated by a slot jet in the central part and two half round jets at the two ends of the merged plume as shown by the solid lines in Figure 2.3. The nonuniform size of the plume is due to the effect of the wind direction with respect to the tower configuration. In general, it is necessary to consider all types of plume merging including all the possible combinations between individual round plumes and modified merged plumes as shown in Figure 2.4. The basic merging criterion considered here is that the plume cross-sections are in contact with each other. An additional criterion is incorporated for the merging between two individual round plumes: the area of the trapezoid should be equal to the sum of the areas of the two half round plumes as circled by the dashed lines in Figure 2.3. When the plumes satisfy these merging criteria, they are merged. The fluxes of the merged plumes are summed to maintain the conservation of fluxes. Moreover, the new shape and the new centroids of the merged plumes are determined, and the integration of the equations is continued. Upon merging, the entrainment and drag functions are altered due to the change in plume shape. The merged plume shape is characterized by the radii B1 and B2 of the two half round plumes, length of the slot jet A, and the angle ϕ (shown in Figure 2.3) between the centerline of the (inclined) plume cross-section and the horizontal line parallel to the y-axis. As the plumes merge a new set of B1, B2, A and ϕ should be determined in order to calculate the entrainment and drag and to check if any other new plume merging occurred. To determine B1, B2, A and ϕ the plumes are classified into two categories: one will be called horizontal for which the total width (WD) of the new merged plume is larger than the total

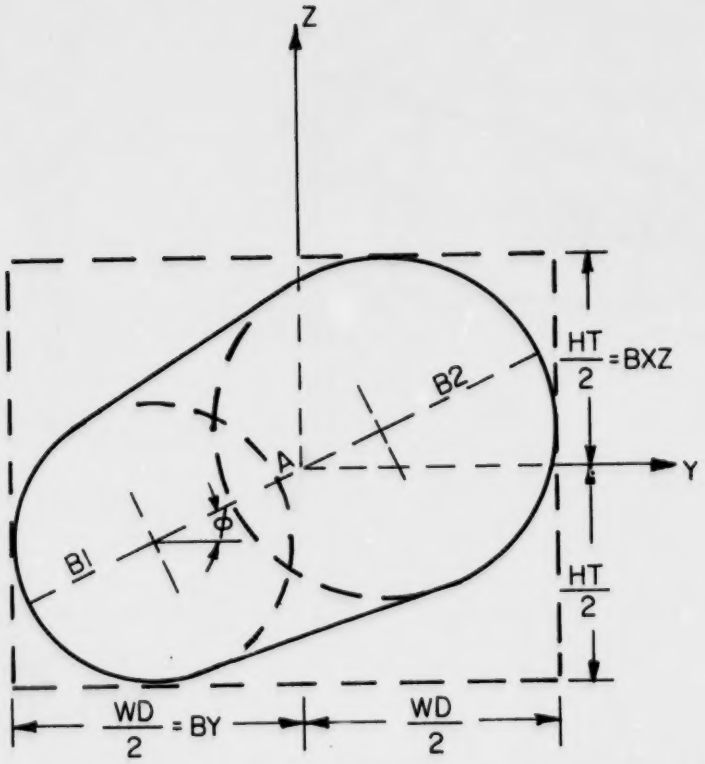

Figure 2.3 Merged Plume Shape

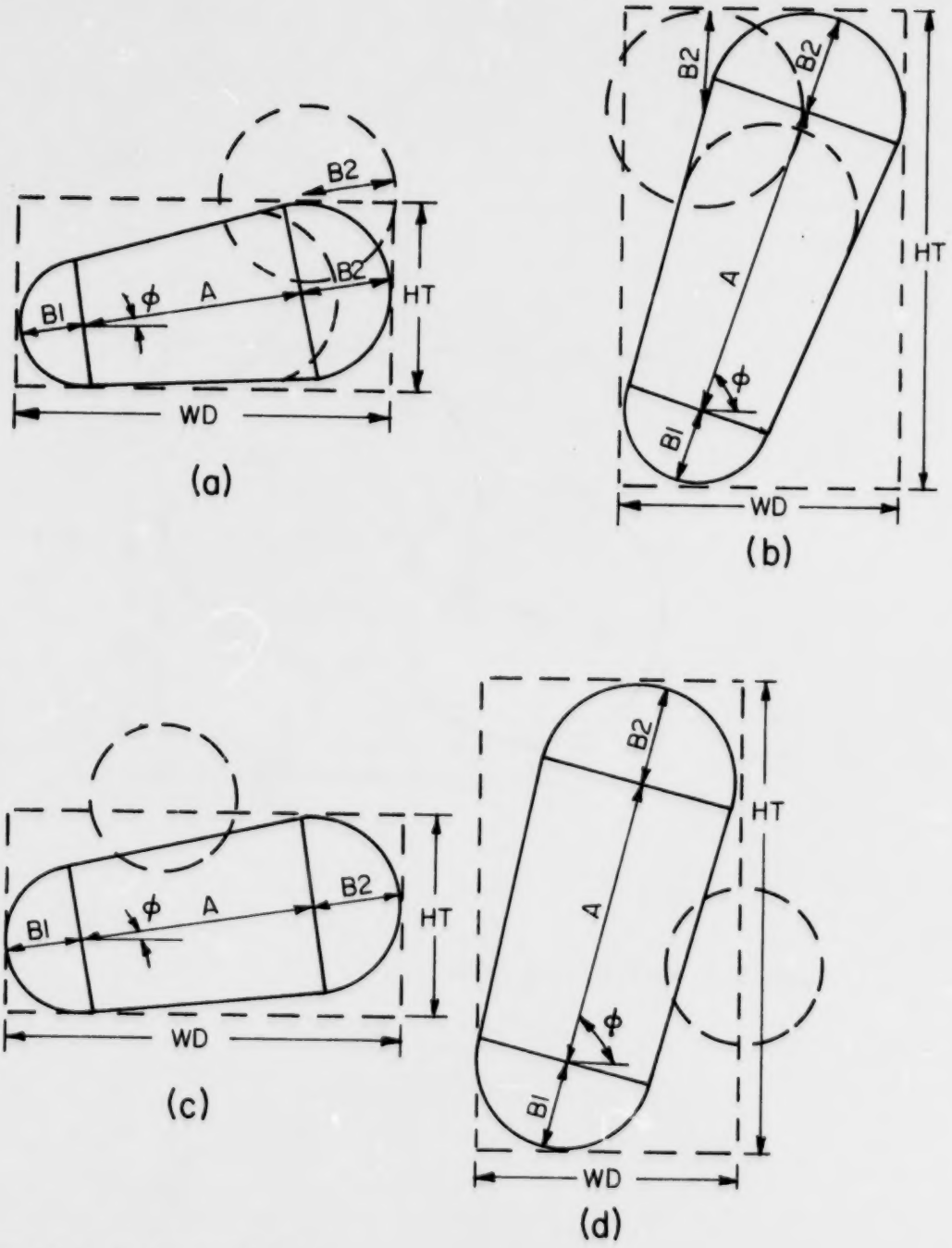

Figure 2.4 Definition Sketch

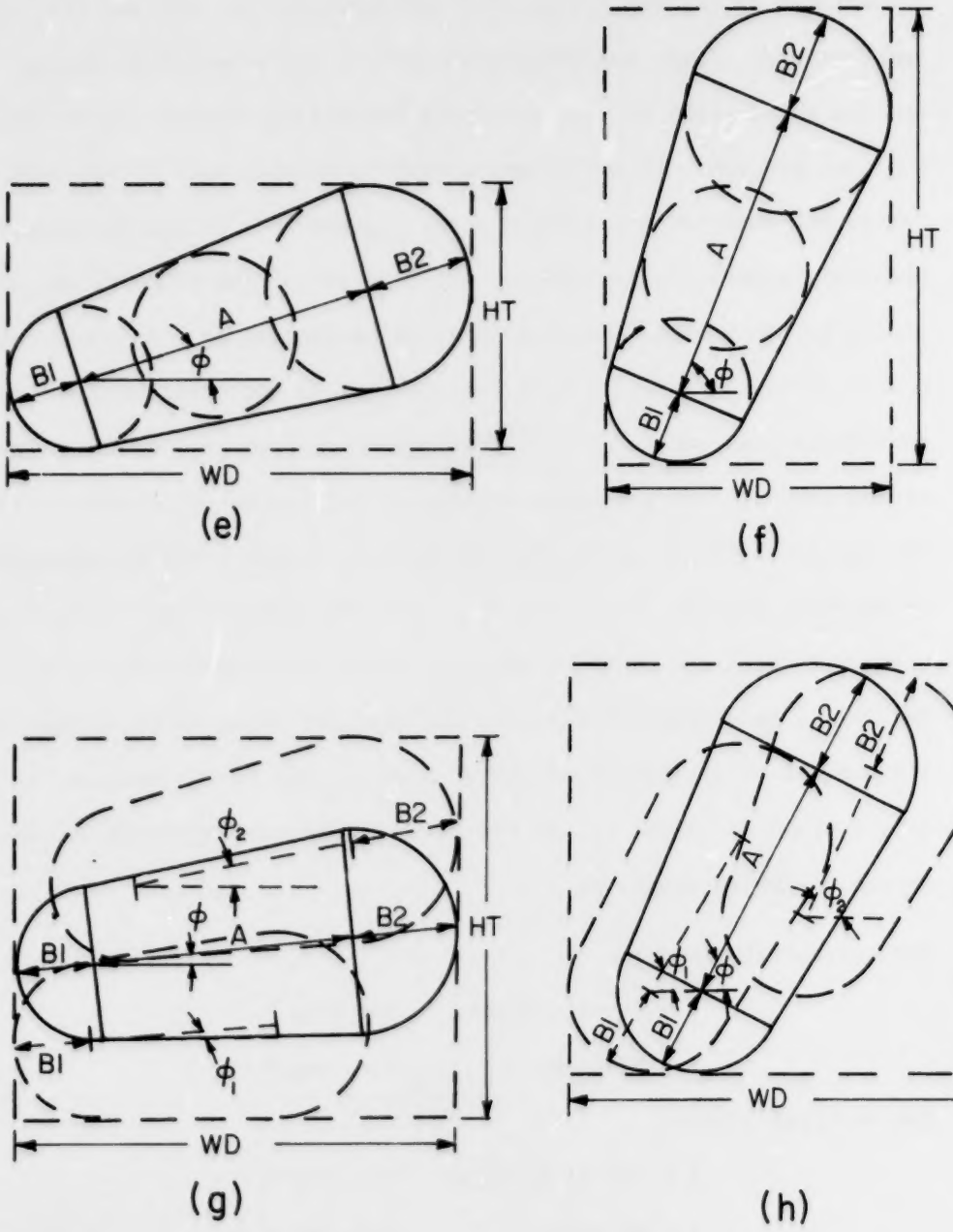

Figure 2.4 Definition Sketch

height (HT), otherwise, it will be called vertical. Both types are illustrated by Figures 2.4(a), (c) and (e); and (b), (d) and (f), respectively. These two categories are not different in substance and the distinction is made primarily for coding convenience in the computer program. B1 and B2 are chosen to be the radii of the left end (or lowest end) and the right end (or highest end) of the horizontal (or vertical) plumes, respectively. The left end of the plume is the end closer to the x-axis. For the cases of merging among individual round plumes as shown by Figure 2.4(a) and (b), ϕ is the angle between the horizontal line and the line connecting the two centers of the merged ending plumes. For the cases of merging between merged plumes, ϕ is the average of angles ϕ_1 and ϕ_2 of the merging plumes 1 and 2, respectively, as shown in Figures 2.4(c) and (d). For the cases of individual round plume 2 joining the merged plume 1 as shown in Figures 2.4(e), (f), (g) and (h), ϕ is assumed to maintain the original value of the merged plume 2 since the resulting merged plume is envisioned to be dominated by the merged plume 2. After B1, B2 and ϕ are determined, A can be calculated by the following equations.

For horizontal plumes:

$$A = (WD-B1-B2)/\cos\phi \quad \text{for } \cos\phi \neq 0$$

$$A = HT-B1-B2 \quad \text{for } \cos\phi = 0$$

For vertical plumes:

$$A = (HT-B1-B2)/\sin\phi \quad \text{for } \sin\phi \neq 0$$

$$A = WD-B1-B2 \quad \text{for } \sin\phi = 0 \qquad (2.37)$$

When the new shape of the merged plume is determined, then the calculation can be performed forward one integration step for the round jets at

the ends and the slot jet (with unit fluxes found by dividing the total fluxes of the slot jet by the finite length A) in the central part. This will result in new values for the radii of the round jets at the ends of the merged plumes, b_{r1} and b_{r2} and the half width and length of the central part slot jet b_s and a. Because of the different entrainment rates for round and slot jets, the calculated plume cross-section determined by b_{r1}, b_{r2}, b_s and a may not be smooth enough to represent a realistic shape. The discontinuities occurring at the junctions of the round and slot jets are demonstrated by the dashed line curve in Figure 2.5. In order to eliminate the discontinuity and to obtain a modified smooth plume cross-section described by B1, B2, and A, the following set of equations is proposed:

$$0.5\pi\ (b_{r1}^2\ U_{r1}\ + b_{r2}^2\ U_{r2}) + 2b_s a U_s =$$

$$[0.5\pi\ (B1^2 + B2^2) + A\ (B1 + B2)] \cdot U \qquad (2.38)$$

$$a + b_{r1} + b_{r2} = A + B1 + B2 \qquad (2.39)$$

$$B1/B2 = b_{r1}/b_{r2} \qquad (2.40)$$

where U_{r1}, U_{r2}, U_s and U are the plume velocities corresponding to the half round jets with radii b_{r1} and b_{r2}, the slot jet with half width b_s, and the overall merged plume defined by B1, B2 and A, respectively.

Equation (2.38) describes the redistribution of the volume flux from the calculated merged plume to the proposed modified plume. Equation (2.39) maintains the same plume length between the calculated and modified plumes. Equation (2.40) keeps the same ratios of the radii of the two half round plumes between calculated and modified plumes.

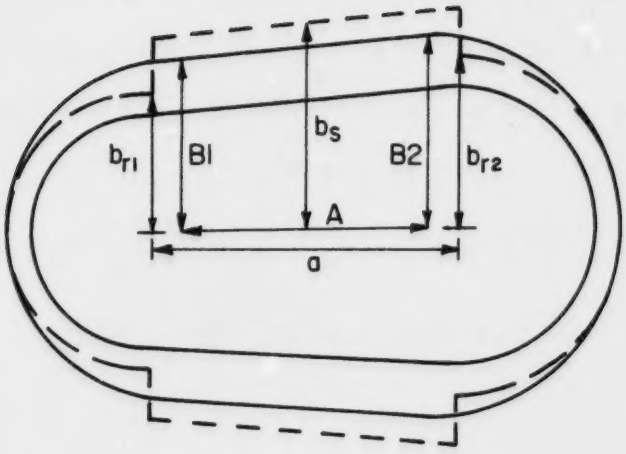

Figure 2.5 Modified Merged Plume Shape

After the modified plume shape is determined, the half width, BY and the half height, BXZ of the merged plume, indicated in Figure 2.3, can be determined by the following equations for the purpose of checking plume merging at the next step:

$$
\begin{aligned}
BY &= 0.5x\ (A \cdot \cos\phi + B1 + B2) && \text{for } \cos\phi \neq 0 \\
&= B1 && \text{for } \cos\phi = 0 \text{ and } B1 \geq B2 \\
&= B2 && \text{for } \cos\phi = 0 \text{ and } B2 > B1 \\
BXZ &= 0.5x\ (A \cdot \sin\phi + B1 + B2) && \text{for } \sin\phi \neq 0 \\
&= B1 && \text{for } \sin\phi = 0 \text{ and } B1 \geq B2 \\
&= B2 && \text{for } \sin\phi = 0 \text{ and } B2 > B1
\end{aligned}
\qquad (2.41)
$$

Due to the uneven change of B1, B2 and A for each integration step, the y-coordinate of the plume centroid also needs to be readjusted. The amount of adjustment Δy noted in Figure 2.6 is

$$
\Delta y = \left[\frac{A_j + B1_j + B2_j}{2} \times \frac{A_{j+1}}{A_j} + B2_{j+1} - \frac{A_{j+1} + B1_{j+1} + B2_{j+1}}{2} \right] \cdot |\cos\phi|
$$

$$
= 0.5x|\cos\phi| \times \left[(B1_j - B2_j) \times \frac{A_{j+1}}{A_j} + B2_{j+1} - B1_{j+1} \right]
$$

where j and j+1 refer to the calculation steps.

With the modified merged plume cross-sectional shape, the entrainment and drag force can be determined and the conservation equations integrated. During the calculation, barring further merging, the length of the slot jet A generally will be reduced and the radii of the two ending round plumes will be increased. Finally, when A diminishes to zero, the shape of the merged plume cross-section becomes practically

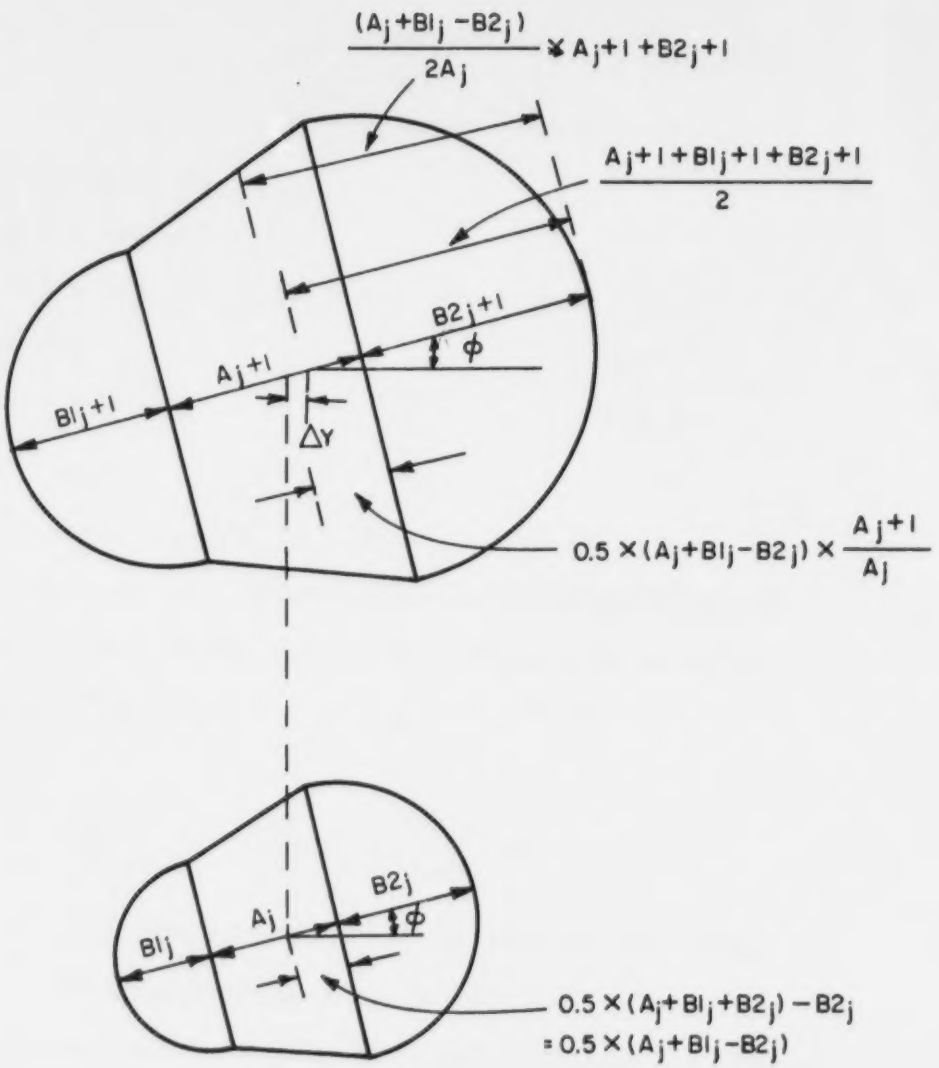

Figure 2.6 Correction of Δy for the Merged Plume

round. At that point, a round plume is again adopted to carry through the final stage of plume calculation.

CHAPTER 3

COMPUTER PROGRAM

The governing equations for predicting the dynamic behavior of multiple cooling tower plumes were presented in Chapter 2. No analytical solution can be obtained due to their complexity as well as the arbitrary ambient conditions in the governing equations. Therefore, a computer program written in Fortran IV language was developed to solve these equations. A standard fourth order Runge-Kutta method was employed in the solution. The inputs to the program include tower exit conditions, ambient conditions, tower configuration, entrainment and drag coefficients, and some control parameters. The basic routine of the computer program begins with inputting data, setting initial conditions (subroutine SETIC) and calculating the first plume (from the tower with the smallest value of x) by setting an indicator IND(I) = 1 for i^{th} individual round plume (subroutines RUNGS and DERIVR). As the calculation continues, the subroutines CHKNWP, ALIGN and PLMERG are called to check for the appearance of any new plumes, to align the existing plumes at approximately the same x-coordinate, and to check for the merging among the existing plumes, respectively, along the direction of the plume trajectory. If new plumes appear (whenever x exceeds the x-location of downstream tower exits), the results for such new plumes are calculated stepwise until the stage is reached to necessitate the checking of the merging criterion. If the plumes merge, the indicator of the i^{th} and the j^{th} plumes are changed to IND(I) = 2 and IND(J) = 0 (J>I). In the subroutine RESETI, the fluxes of the merged plumes are added together, and the initial conditions for the merged plumes are

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reset. The subroutines DERIVR and DERIVS are called to calculate the plume half widths and velocities of the round and slot jets in order to determine the shape of the modified merged plume. Then, subroutine DERIVE is used to calculate the dynamic properties of the modified merged plume. The calculation stops when the integration step number is equal to the desired (input) step number. The outputs include the input information, and the calculated plume properties such as temperature, excess temperature, moisture, excess moisture, half width and trajectory at visible, merging and final stages of the plumes. The detailed listings and examples of the input and output are presented in Appendix A. The general structure of the computer program is described by the flow chart shown in Figure 3.1. Some important variables in the text and program are compiled and listed in Appendix B. The complete computer program is presented in Appendix C.

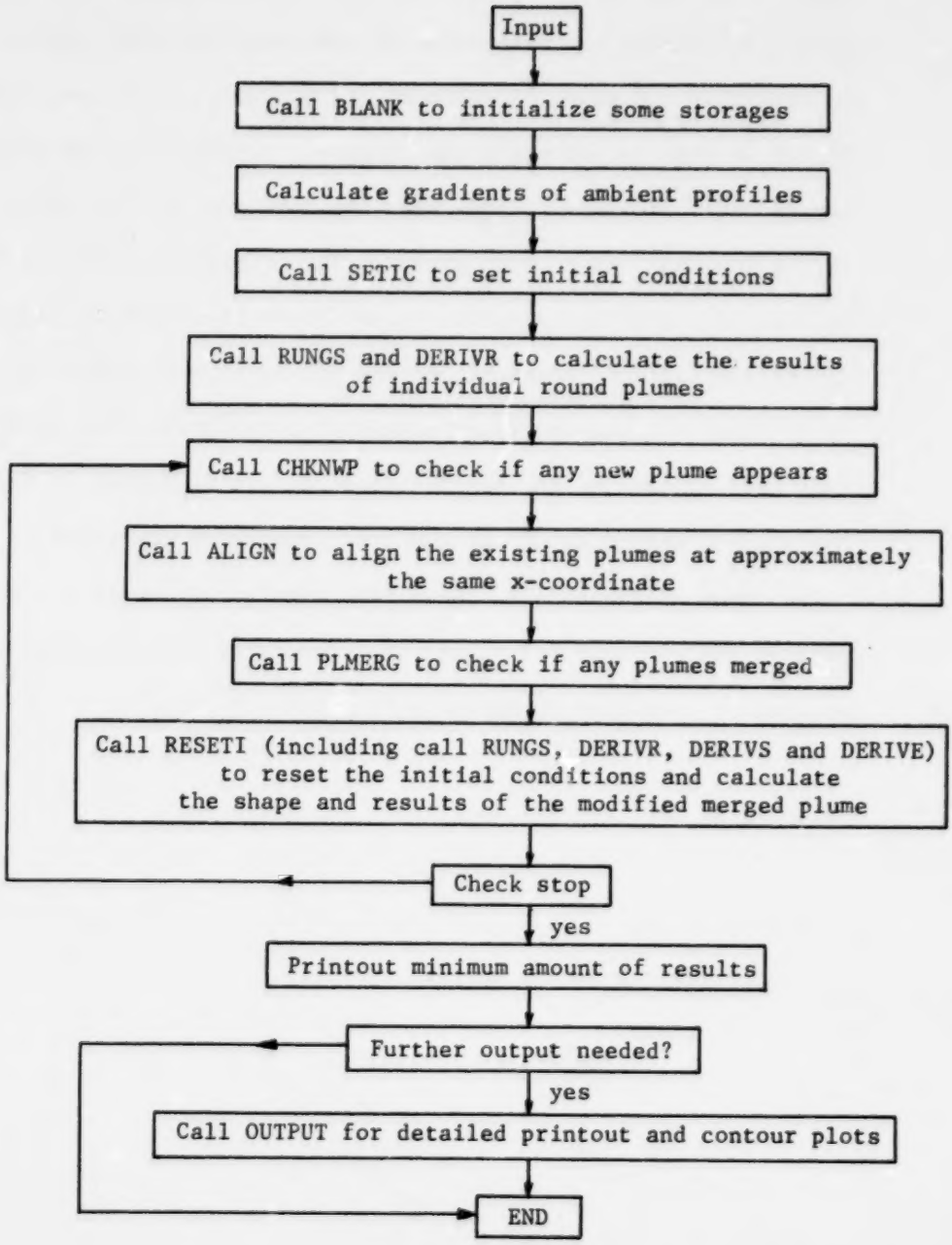
Input
Call BLANK to initialize some storages
Calculate gradients of ambient profiles
Call SETIC to set initial conditions
Call RUNGS and DERIVR to calculate the results of individual round plumes
Call CHKNWP to check if any new plume appears
Call ALIGN to align the existing plumes at approximately the same x-coordinate
Call PLMERG to check if any plumes merged
Call RESETI (including call RUNGS, DERIVR, DERIVS and DERIVE) to reset the initial conditions and calculate the shape and results of the modified merged plume
Check stop
yes
Printout minimum amount of results
Further output needed?
yes
Call OUTPUT for detailed printout and contour plots
END

Figure 3.1 Flow Chart of the Computer Program

CHAPTER 4

RESULTS, COMPARISONS AND DISCUSSIONS

In this chapter, four example cases are presented. The results of the present theory are also compared with the laboratory results of Fan (1967), Chan et al. (1974), and field data from TVA (Carpenter et al., 1968).

In the example runs, a line array of four cooling towers and a round array of five cooling towers are considered. For the cases with the line array, three wind directions (i.e. 0°, 90°, and 135° with respect to the tower array) are chosen. The input data cards are shown in Table 4.1, which include the number of towers, the desired number of calculation steps, control parameters, tower configuration, ambient levels, temperature profile, humidity profile, wind velocity profile, tower exit conditions, coefficients of contour plots and heading of plots. Normally, the outputs consist only of the input information, the results at the merging points, and those at the beginning and ending points of the visible phases of plumes. However, detailed printouts and/or contour plots can also be provided by the program upon request. The contour plots of excess temperature, humidity and liquid phase moisture for these examples are shown in Figures 4.1 through 4.12. The plots represent the distribution of the highest values projected onto the X-Z plane. Detailed explanations of the input and output parameters are presented in Appendix A.

Three sets of data from Fan (1967) for a single jet, one set from Chan et al. (1974) for six towers and two sets from Carpenter et al. (1968) for a single tower and multiple towers are chosen for comparison with the model.

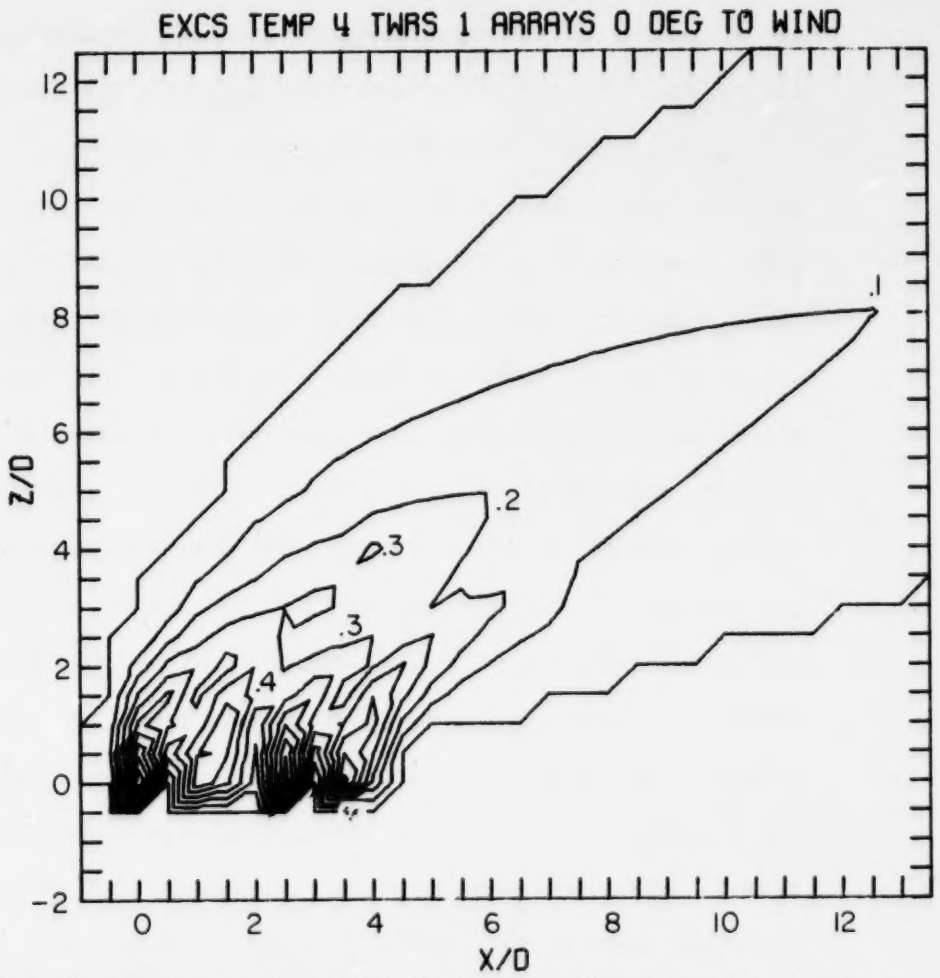

Figure 4.1 Excess Temperature Distribution for the Case of 4 Towers in Linear Array and 0° to Wind Direction

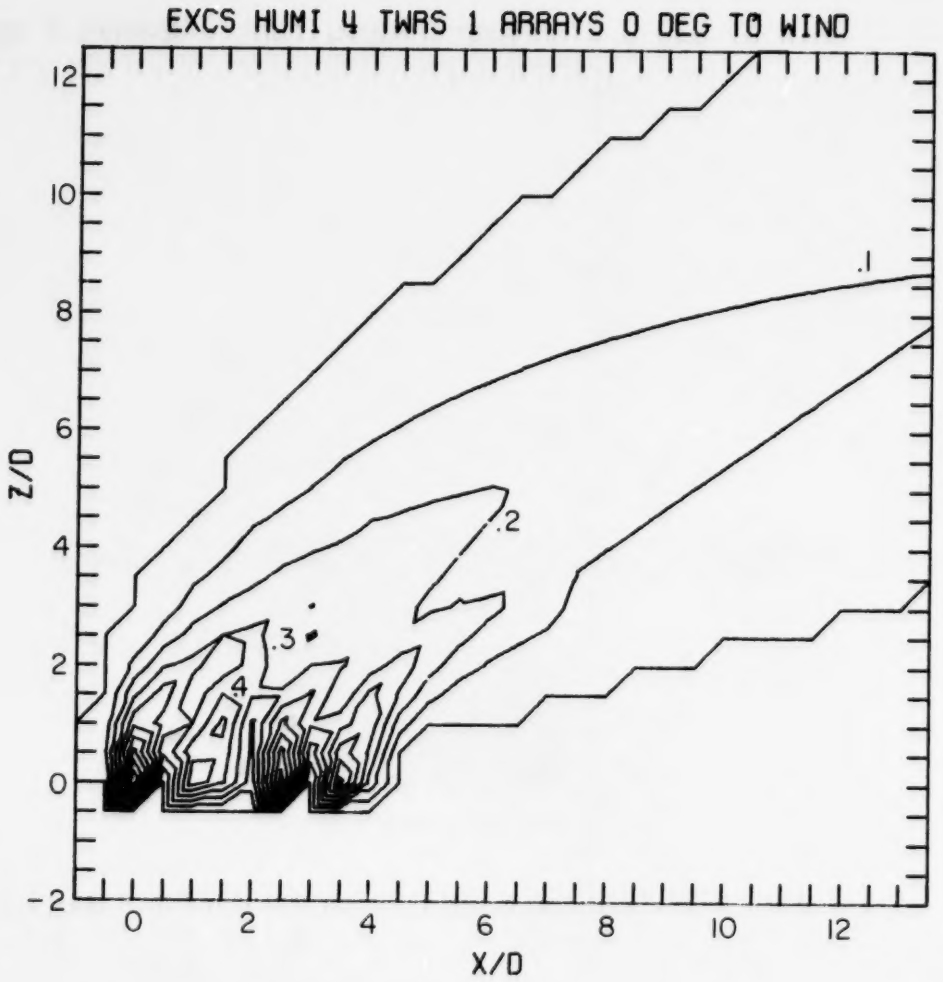

Figure 4.2 Excess Humidity Distribution for the Case of 4 Towers in Linear Array and 0° to Wind Direction

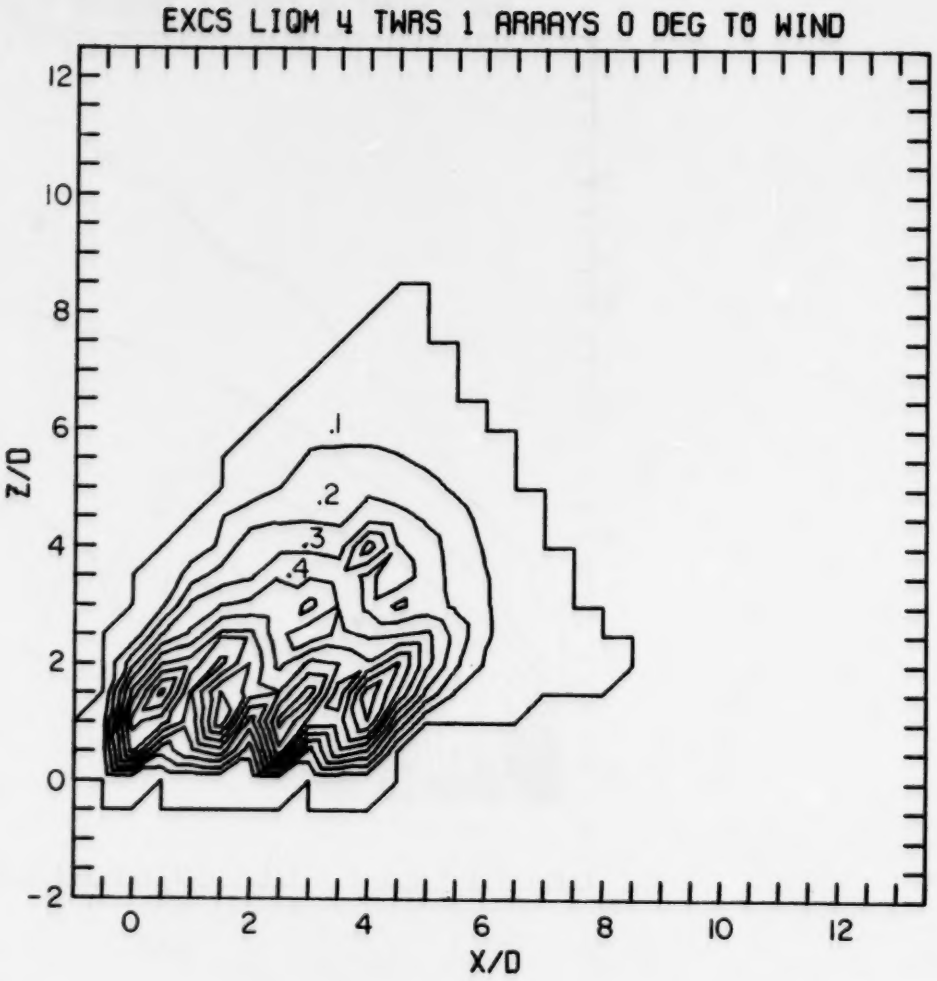

Figure 4.3 Excess Liquid Phase Moisture Distribution for the Case of 4 Towers in Linear Array and 0° to Wind Direction

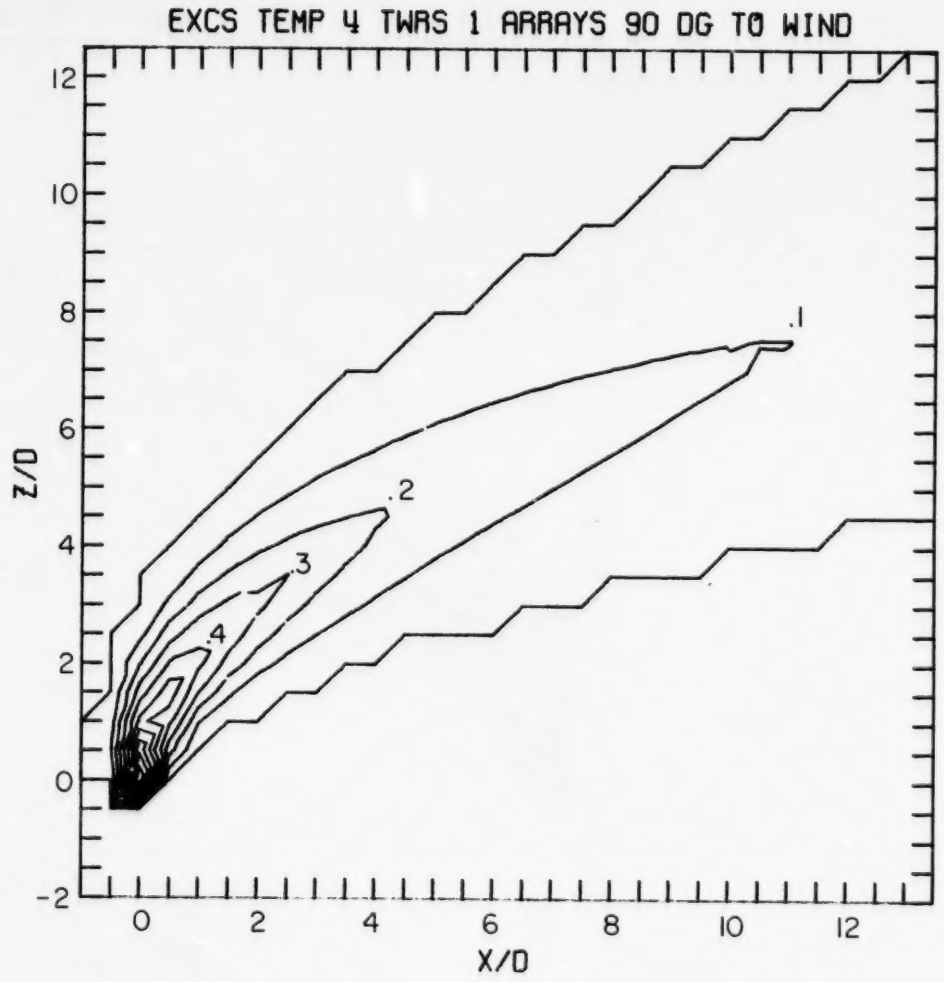

Figure 4.4 Excess Temperature Distribution for the Case of 4 Towers in Linear Array and 90° to Wind Direction

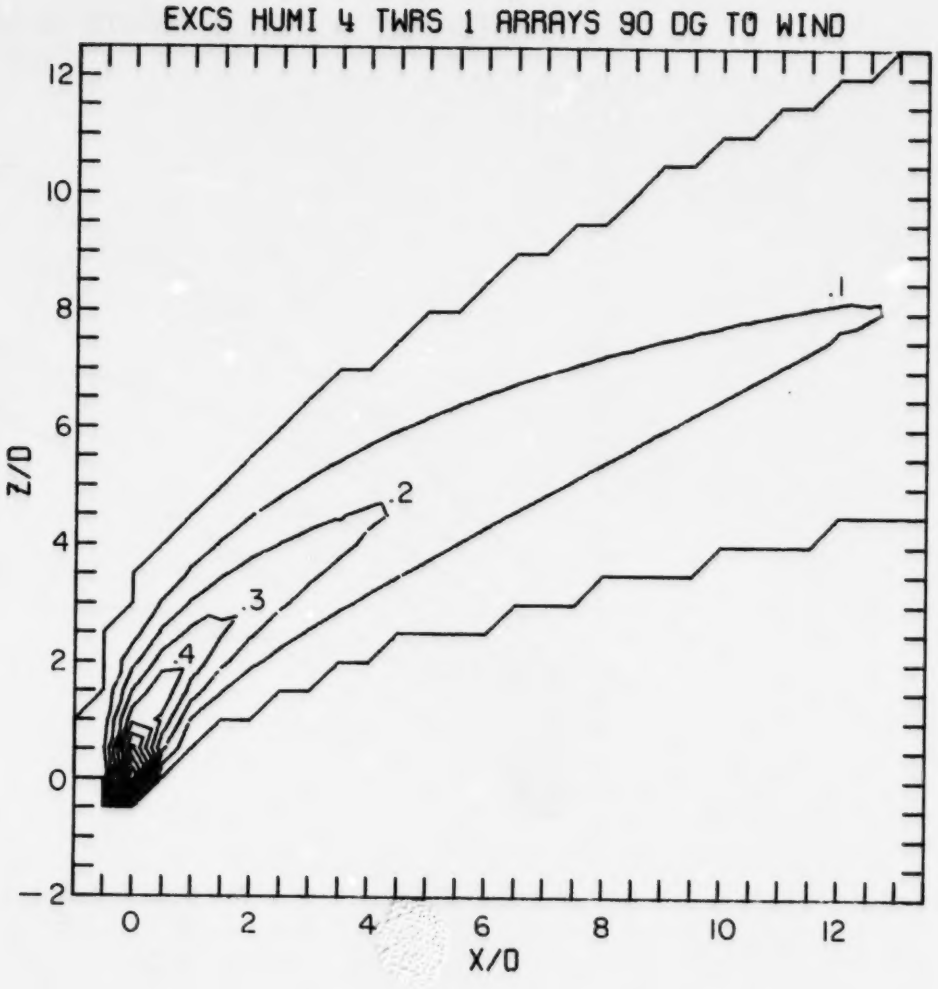

Figure 4.5 Excess Humidity Distribution for the Case of 4 Towers in Linear Array and 90° to Wind Direction

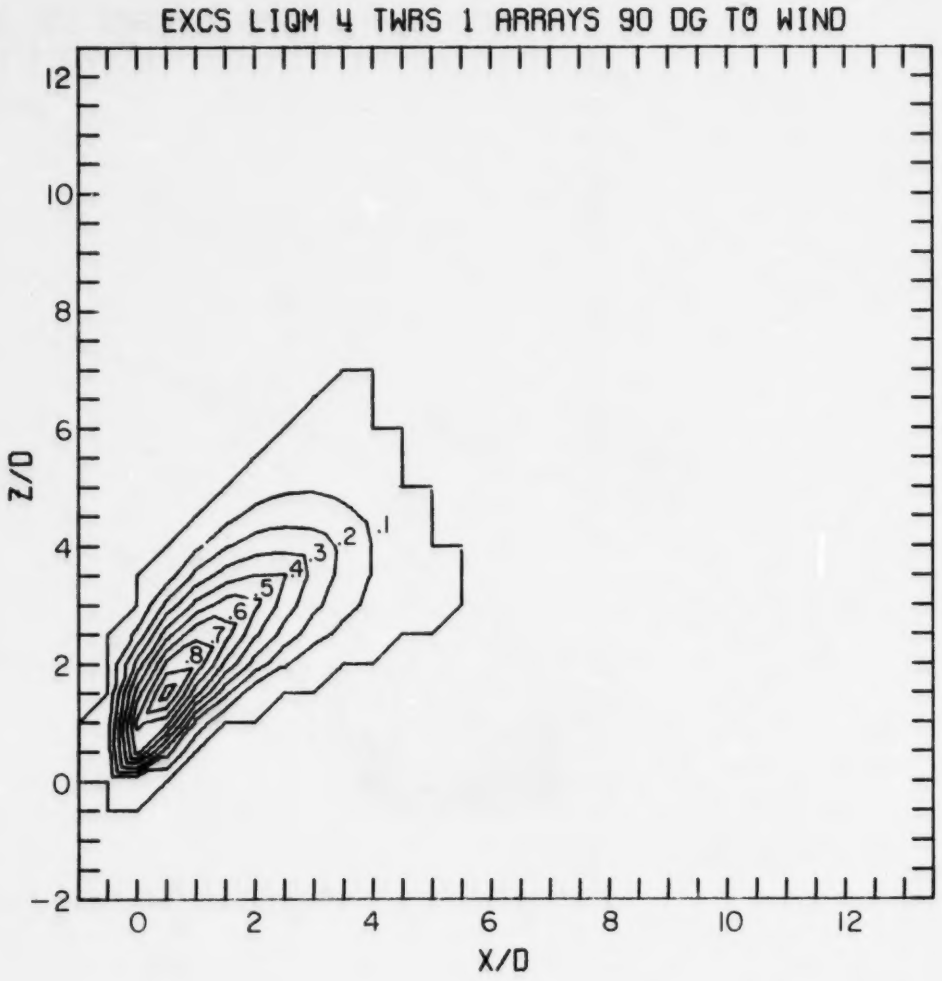

Figure 4.6 Excess Liquid Phase Moisture Distribution for the Case of 4 Towers in Linear Array and 90° to Wind Direction

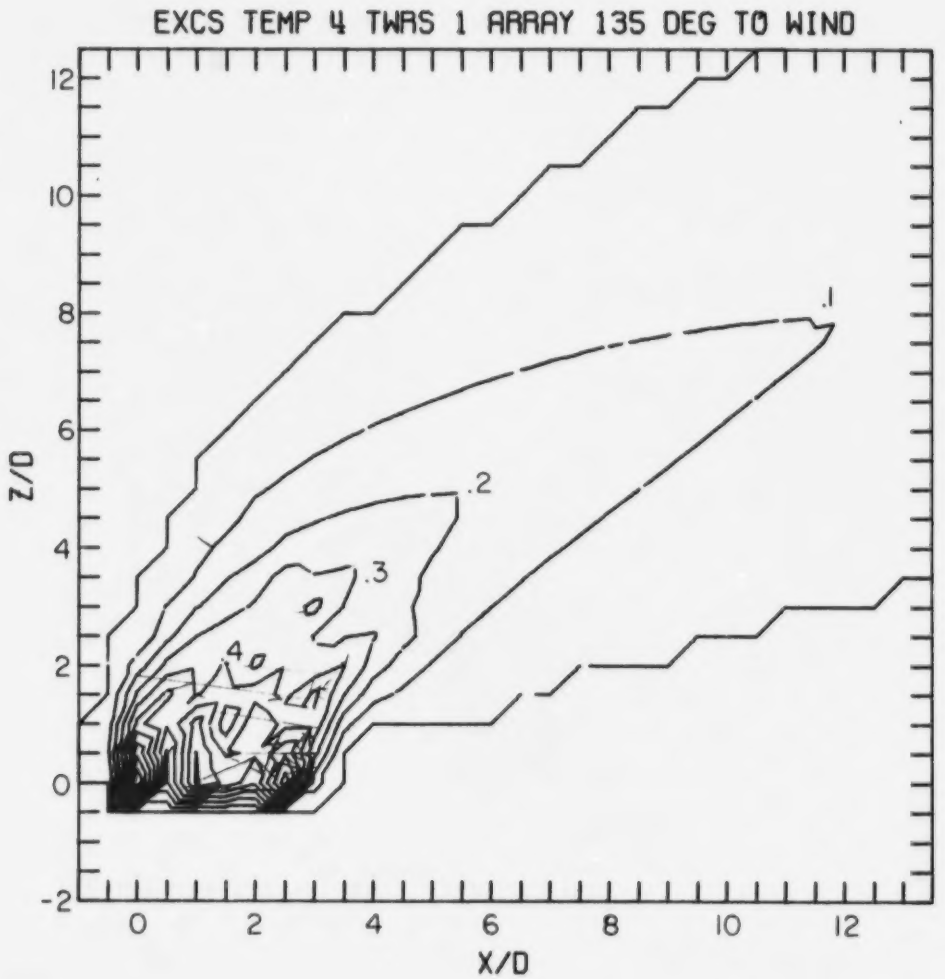

Figure 4.7 Excess Temperature Distribution for the Case of 4 Towers in Linear Array and 135° to Wind Direction

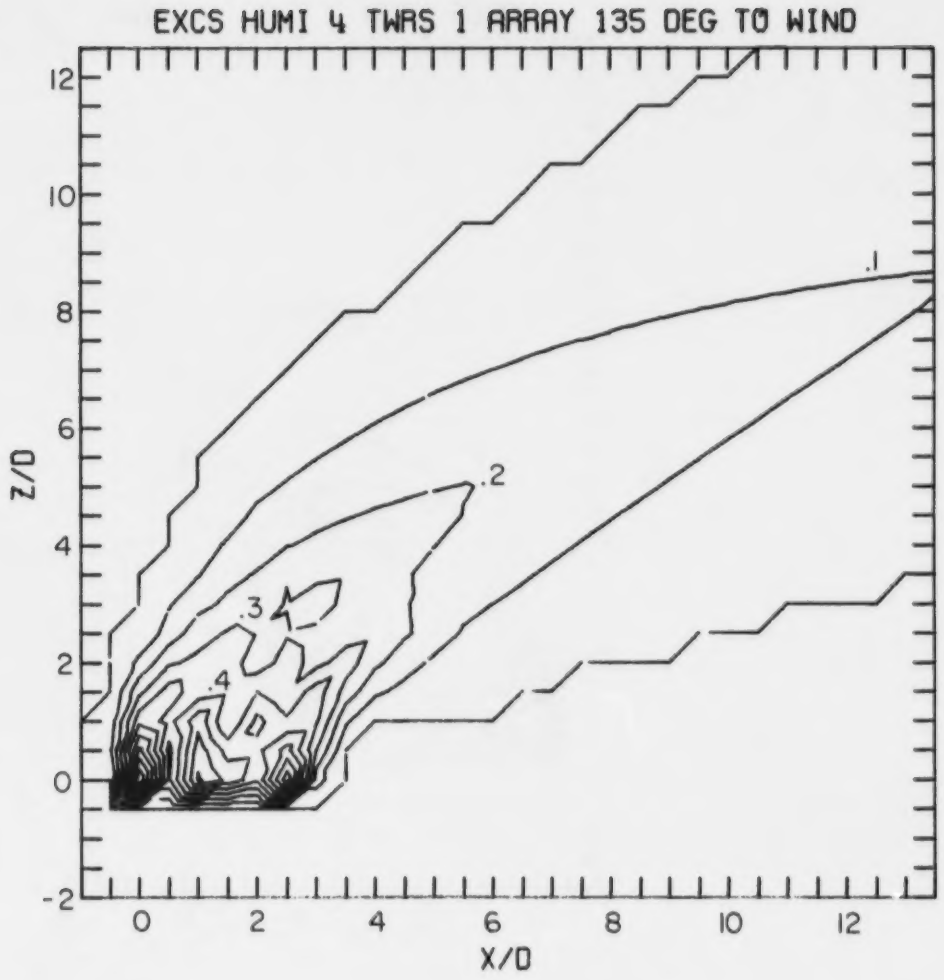

Figure 4.8 Excess Humidity Distribution for the Case of 4 Towers in Linear Array and 135° to Wind Direction

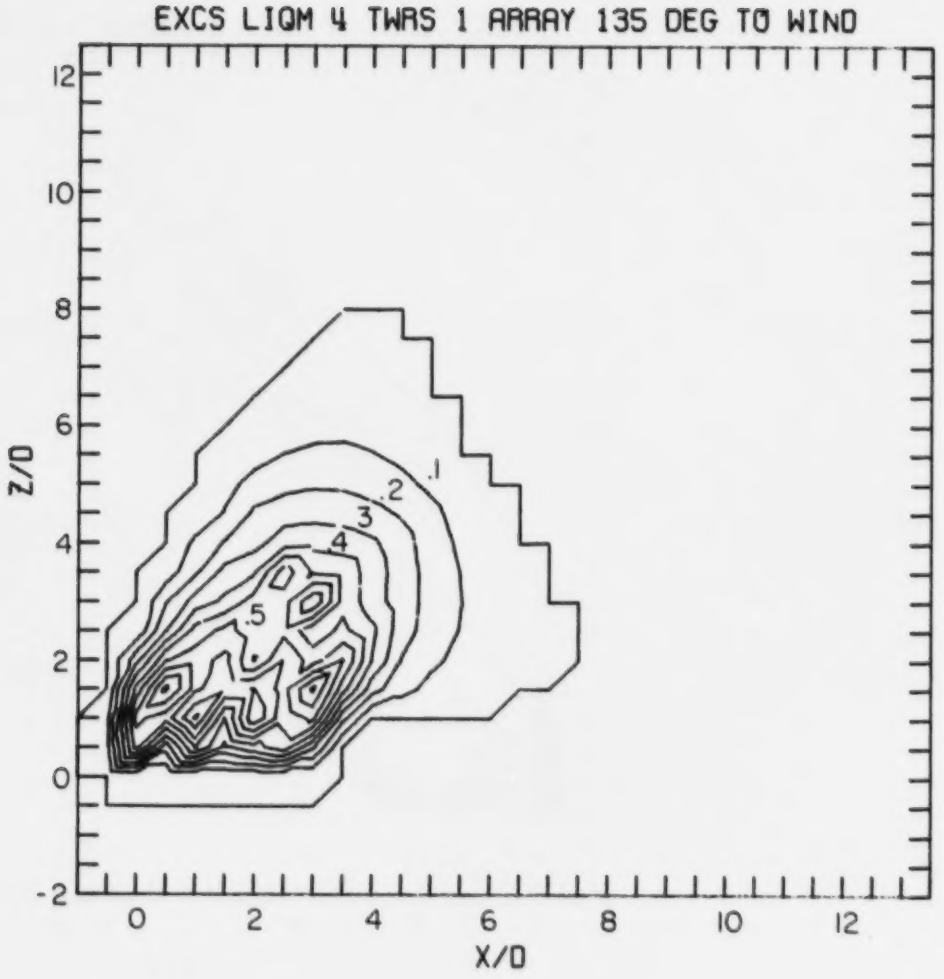

Figure 4.9 Excess Liquid Phase Moisture Distribution for the Case of 4 Towers in Linear Array and 135° to Wind Direction

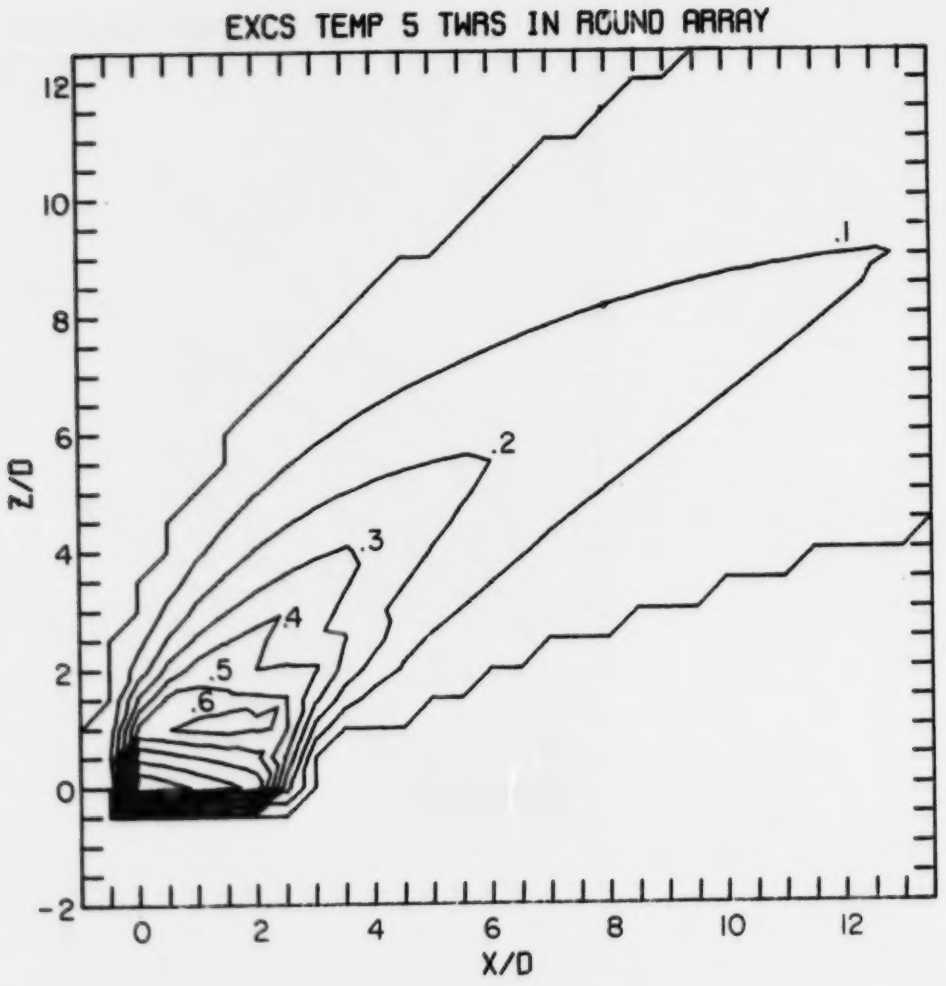

Figure 4.10 Excess Temperature Distribution for the Case of 5 Towers in Round Array

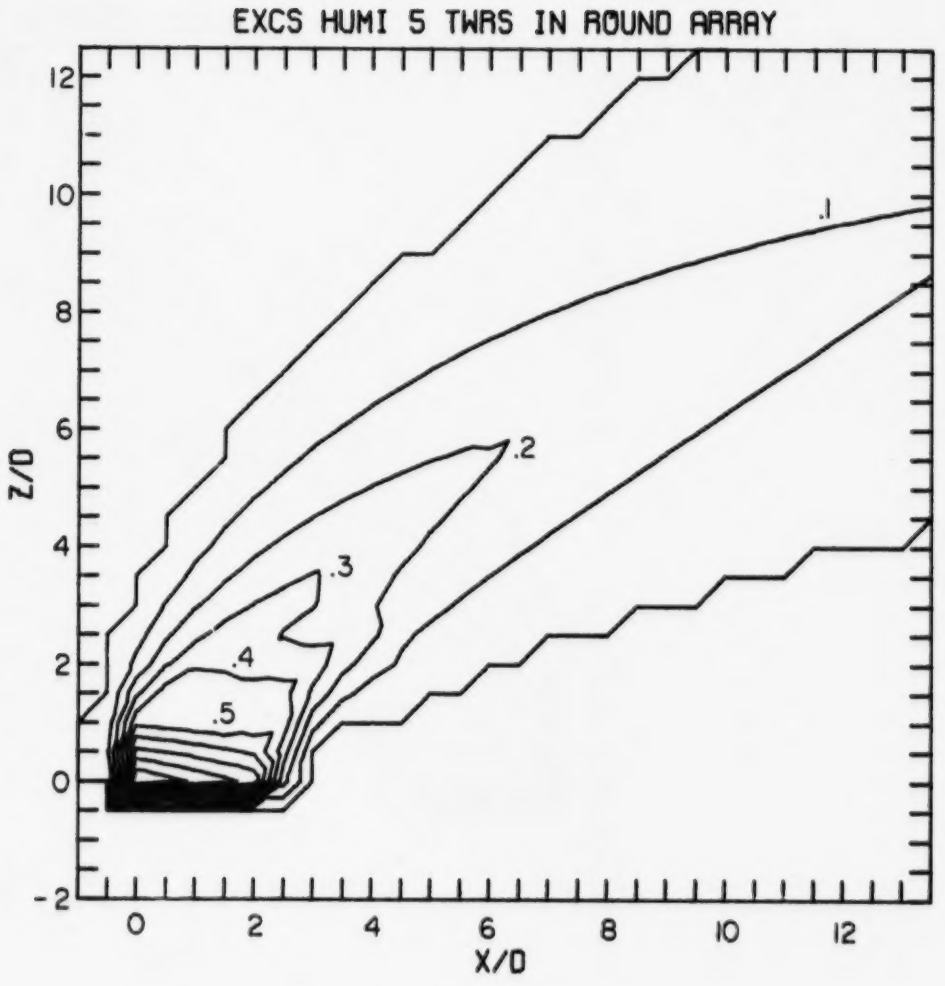

Figure 4.11 Excess Humidity Distribution for the Case of 5 Towers in Round Array

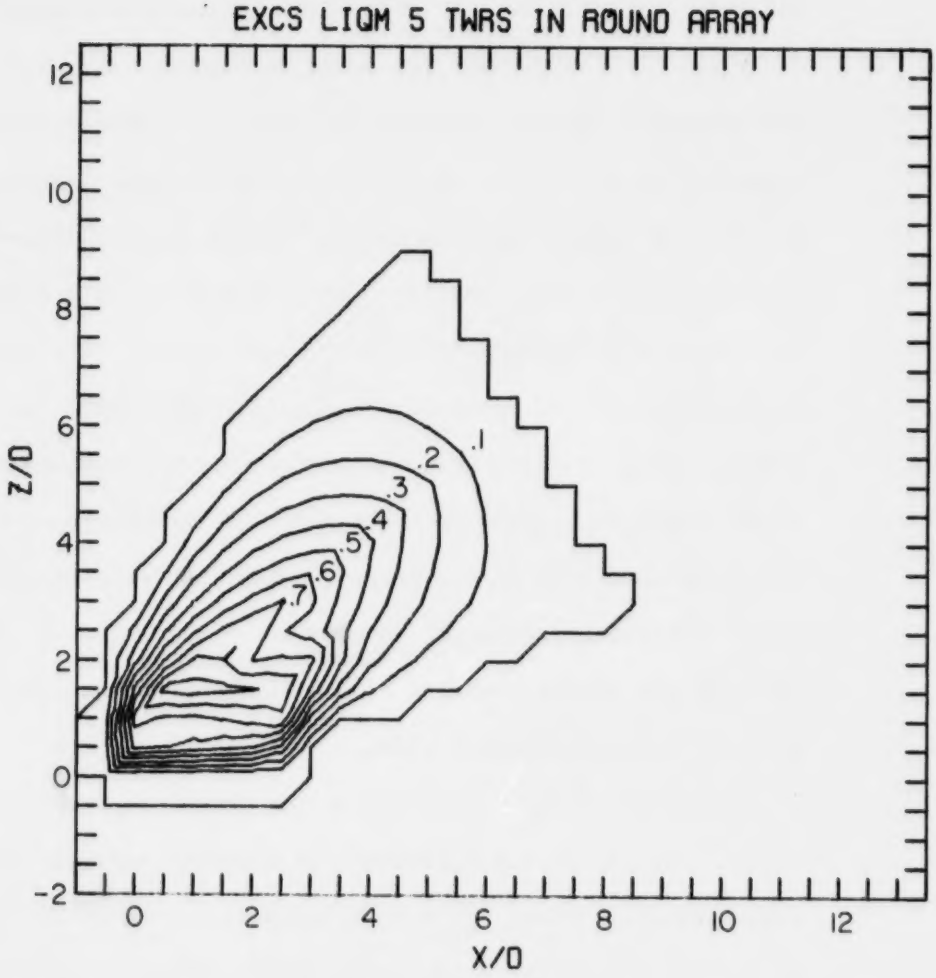

Figure 4.12 Excess Liquid Phase Moisture Distribution for the Case of 5 Towers in Round Array

The input data cards for these cases are shown in Tables 4.2 through 4.5. The ambient conditions for the data from Fan and Chan et al. are uniform. The velocity and temperature at the tower exit and ambient are chosen to satisfy the given values of densimetric Froude number F and velocity ratio K. The predicted results of dilution, plume trajectory and width for Fan's cases are shown in Figures 4.13, 4.14 and 4.15, and are compared with his experimental results. The comparisons are generally good. The predicted excess temperature distribution for the six tower case from Chan et al. is shown in Figure 4.16, together with the experimental results. In this case the six towers are in one line array and the ambient flow to it is normal. The contour plot is for the distribution of values in the central x-z plane. It seems that the present model tends to overpredict the excess temperature. The main reason might be because of the neglect of the effect of the mixing in the plume wake zone in the present model. However it should also be noted that the experimental results of Chan et al. may have been influenced by the blockage of the flow by the model towers due to the finite width of the experimental flume.

The field results from TVA at the Paradise power plant include two cases. One is for a single tower in a stable ambient (TVA-11, potential temperature gradient $\frac{\partial\theta}{\partial z} = 0.59$ °k/100m, $0 < \frac{\partial\theta}{\partial z} \leq 1.0$ °k/m). The other is for two towers in an ambient with a temperature inversion (TVA-14, $\frac{\partial\theta}{\partial z} = 1.42$ °k/100m > 1.0 °k/m). Since only the average temperature gradient and average wind velocities at a few levels were available only rough estimates of ambient temperature and wind velocity profiles were constructed based on the limited data.

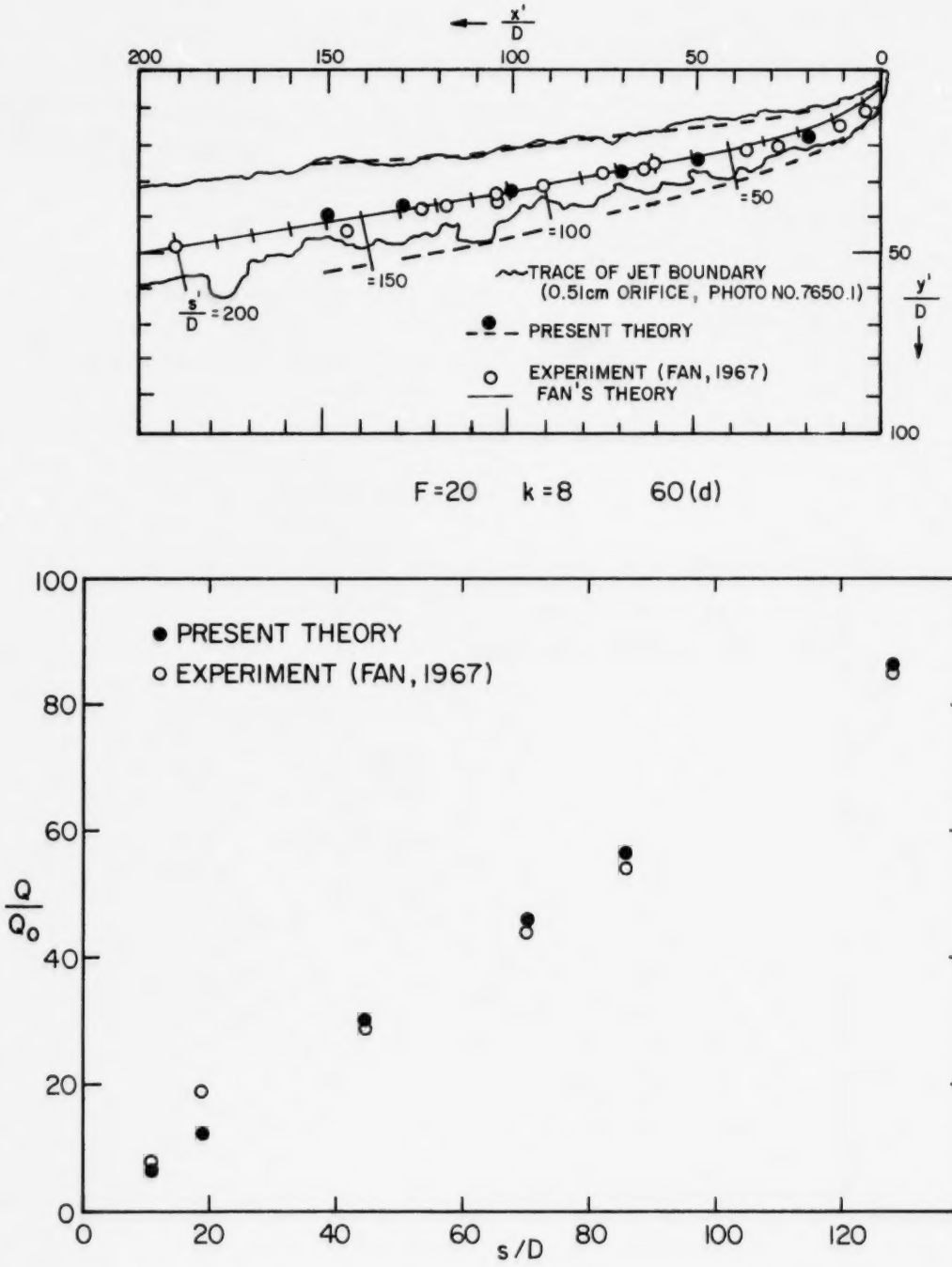

Figure 4.13 Comparisons of Plume Trajectory, Width and Dilution Between the Present Theory and Fan's (1967) Experiments for F = 20 and K = 8

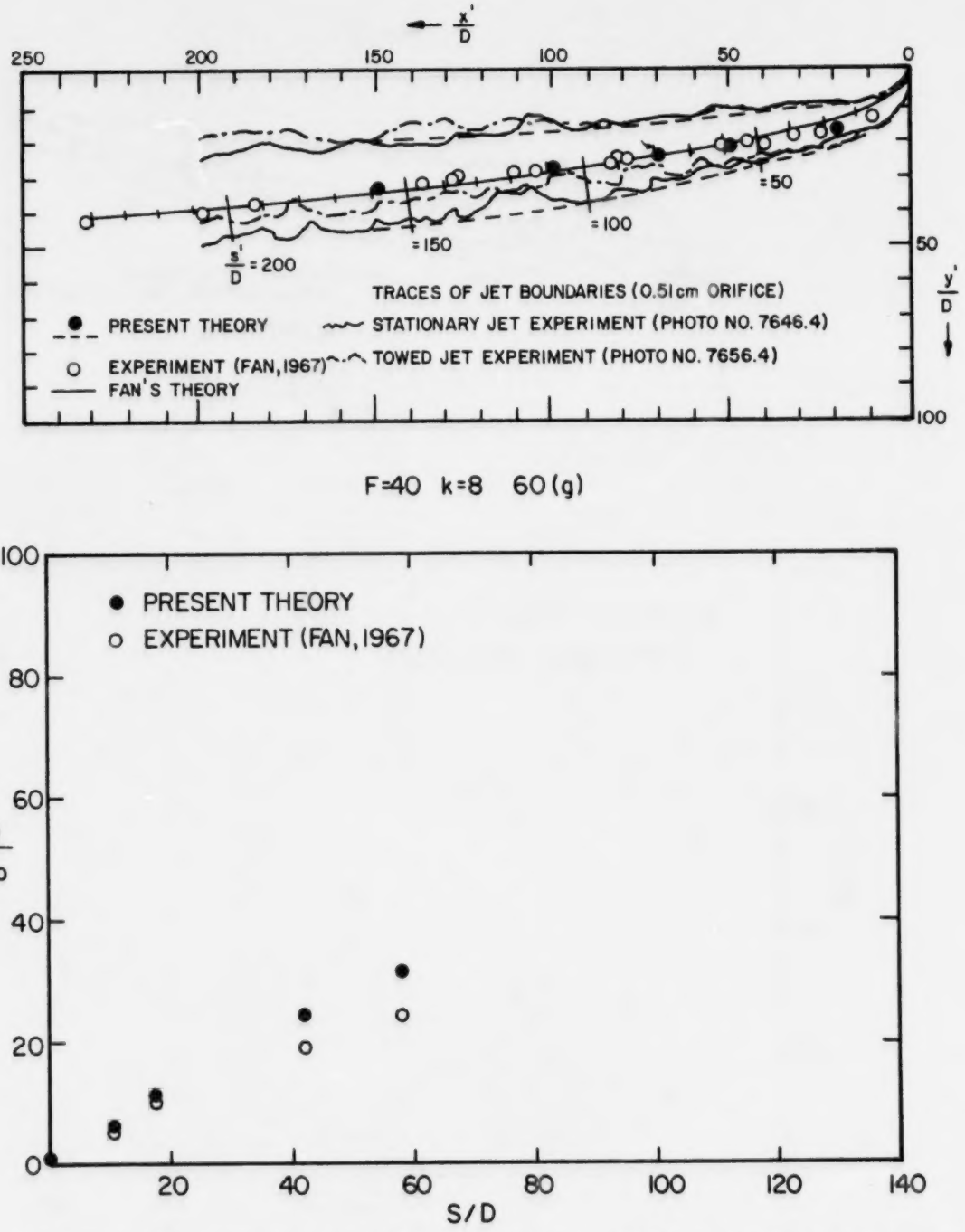

Figure 4.14 Comparisons of Plume Trajectory, Width and Dilution Between the Present Theory and Fan's (1967) Experiments for F = 40 and K = 8

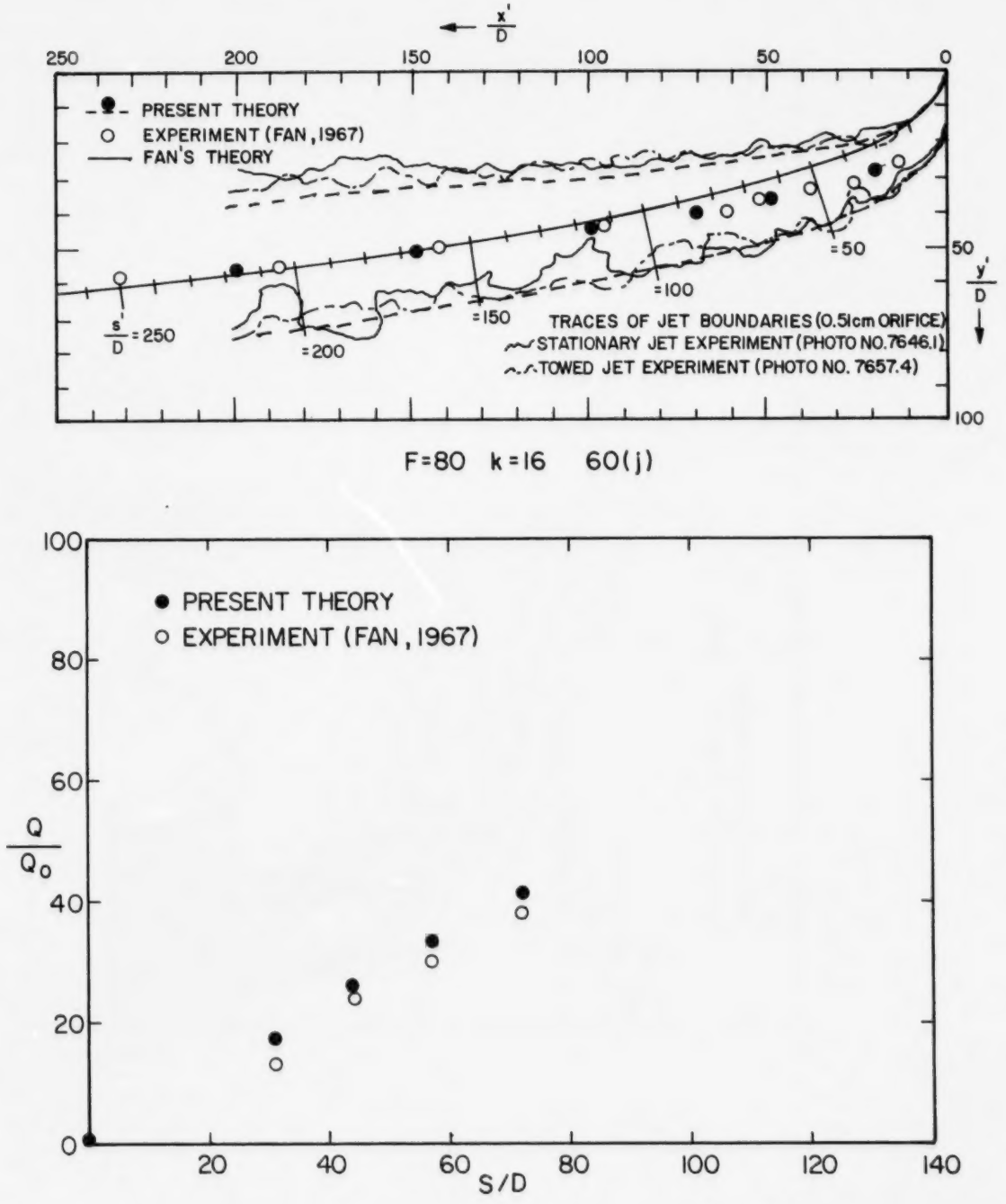

Figure 4.15 Comparisons of Plume Trajectory, Width and Dilution Between the Present Theory and Fan's (1967) Experiments for F = 80 and k = 16

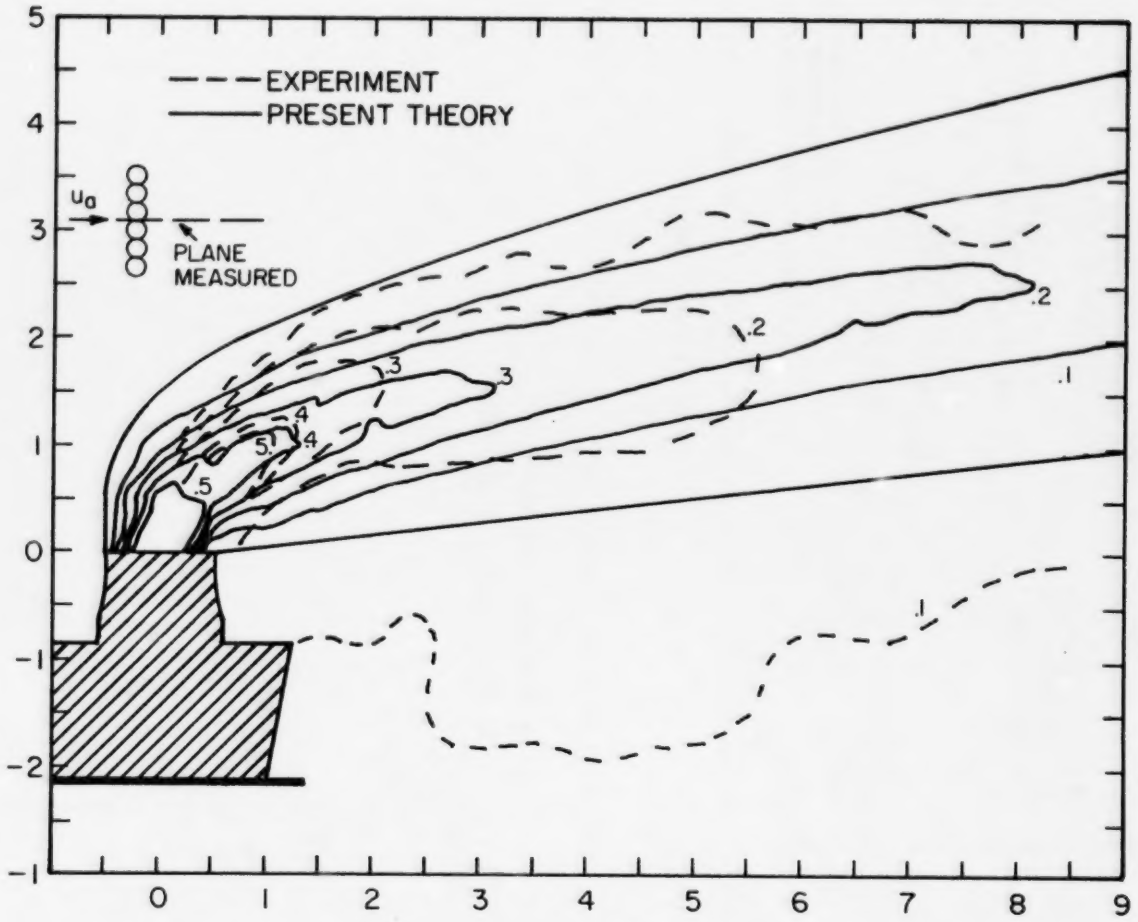

Figure 4.16 Comparisons of Plume Excess Temperature Between the Present Theory and Chan et al.'s (1974) Experiments for F = 4 and K = 1.02

Three ambient relative humidity profiles (100%, 70%, 0%) associated with the relative temperature profiles were generated and tested. The exit plume humidities were assumed 100% (saturated) except for one dry plume case which is 0% for ambient and exit humidities. The input data cards are presented in Tables 4.4 and 4.5. The predicted results and the comparisons are shown in Figures 4.17 and 4.18. From the variations of plume trajectory for different ambient humidity conditions, the effect of the ambient humidity can be seen to be quite significant. Similar conclusions could be drawn for the effect of ambient temperature and wind velocity. The present model overpredicts the plume trajectories for TVA's cases. This could be due to the incomplete information of the ambient conditions and the neglect of drift in the tower initial conditions. Adequate ambient and source conditions are mandatory for proper model validation.

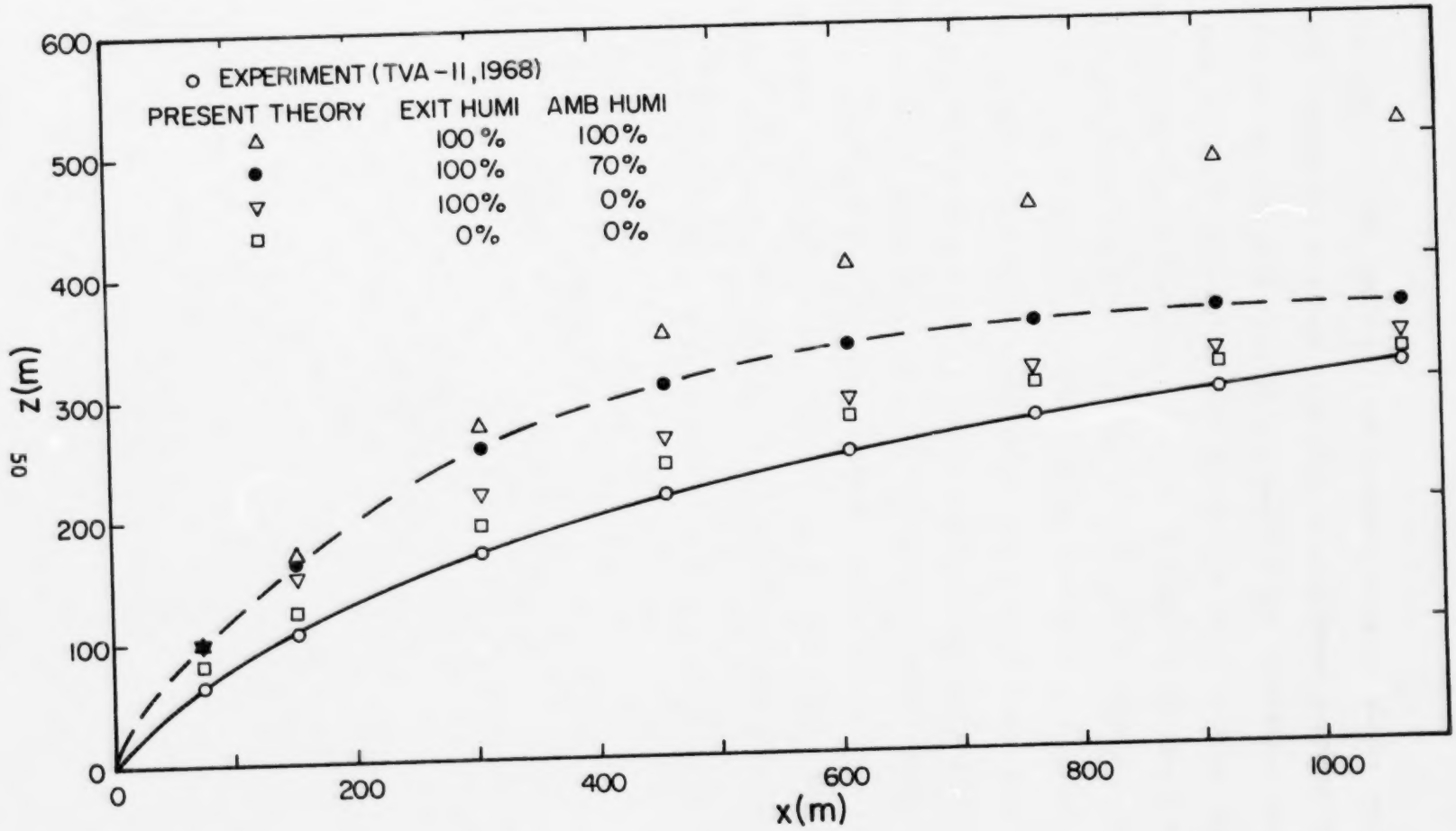

Figure 4.17 Comparisons of Plume Trajectories Between the Present Theory and TVA (1968, TVA-11, single tower) Field Data in a Stable Atmospheric Condition ($\partial\theta/\partial z$=0.59°K/100 m)

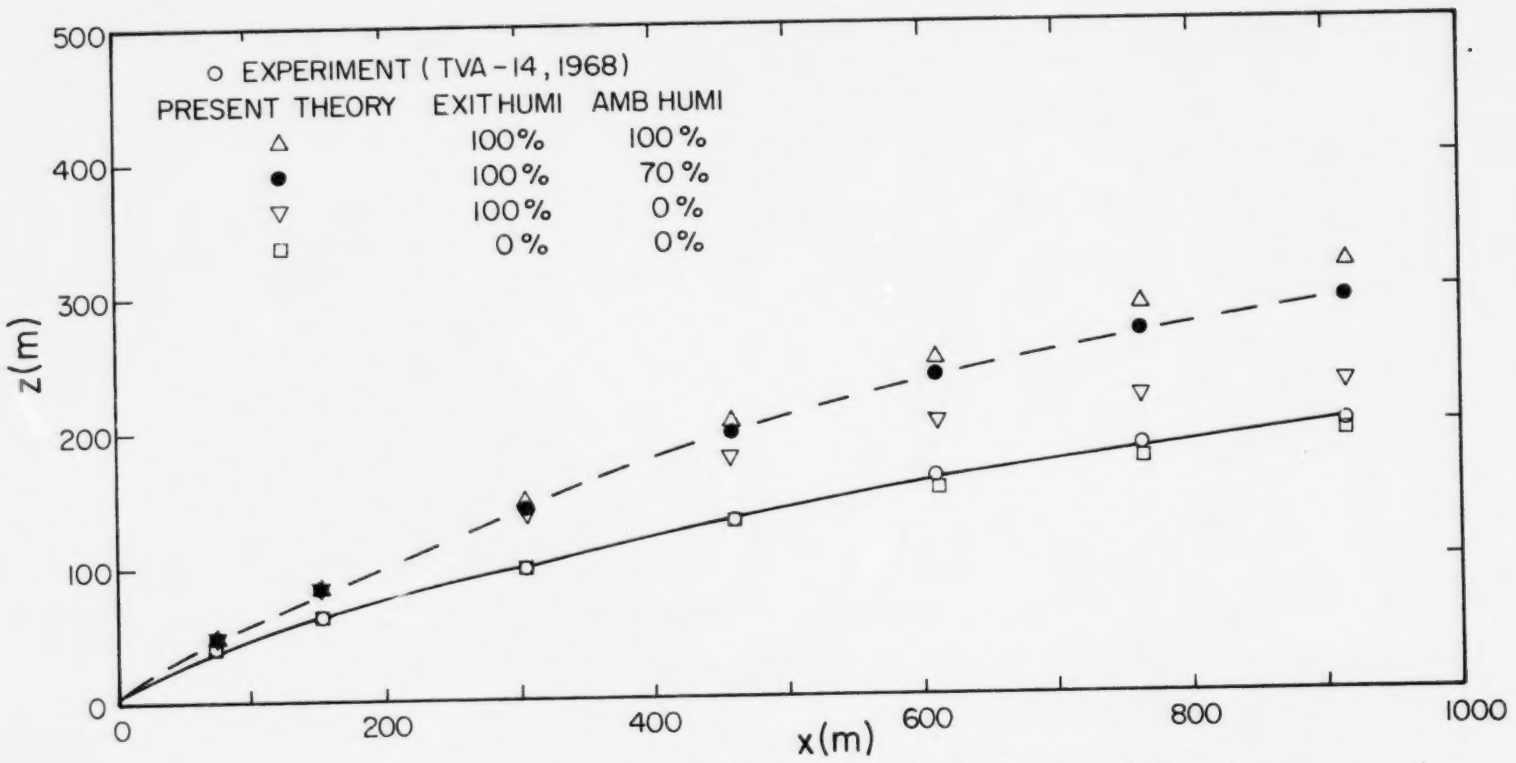

Figure 4.18 Comparisons of Plume Trajectories Between the Present Theory and TVA (1968, TVA, two towers) Field Data in an Atmosphere with an Inversion ($\partial\theta/\partial z$=1.42°K/100 m)

Table 4.1 Input Data Cards for Example Cases (different Wind Directions to a Line Array (3 cases) and Round Array (one case) of Towers)

```
CASE (1)  4 TOWERS IN ONE ARRAY   0 DEGREES TO WIND
    4 120  30  30  11
    0   0   0   3  10   0   1   1   1   1   1
   .00000  11.45000  22.90000  34.35000
   .00000   .00000    .00000    .00000
   .00000 100.00000 200.00000
 10.50000  10.30000  10.10000
 70.00000  70.00000  70.00000
  4.10000   5.22504   5.76969   4.10000   5.22504   5.76969   4.10000   5.22504
  5.76969   4.10000   5.22504   5.76969
  9.44880  10.26800  31.90000    .02821    .00000
  5.00000   5.00000   0   0   0   0
EXCS TEMP 4 TWRS 1 ARRAYS 0 DEG TO WIND Z/D                    X/D
EXCS HUMI 4 TWRS 1 ARRAYS 0 DEG TO WIND Z/D                    X/D
EXCS LIQM 4 TWRS 1 ARRAYS 0 DEG TO WIND Z/D                    X/D

CASE (2)  4 TOWERS IN ONE ARRAY  90 DEGREES TO WIND
    4 120  30  30  11
    0   0   0   3  10   0   1   1   1   1   1
   .00000    .00000    .00000    .00000
   .00000  11.45000  22.90000  34.35000
   .00000 100.00000 200.00000
 10.50000  10.30000  10.10000
 70.00000  70.00000  70.00000
  4.10000   5.22504   5.76969   4.10000   5.22504   5.76969   4.10000   5.22504
  5.76969   4.10000   5.22504   5.76969
  9.44880  10.26800  31.90000    .02821    .00000
  5.00000   5.00000   0   0   0   0
EXCS TEMP 4 TWRS 1 ARRAYS 90 DG TO WIND Z/D                    X/D
EXCS HUMI 4 TWRS 1 ARRAYS 90 DG TO WIND Z/D                    X/D
EXCS LIQM 4 TWRS 1 ARRAYS 90 DG TO WIND Z/D                    X/D

CASE (3)  4 TOWERS IN ONE ARRAY 135 DEGREES TO WIND
    4 120  30  30  11
    0   0   0   3  10   0   1   1   1   1   1
   .00000   8.10000  16.19000  24.29000
   .00000   8.10000  16.19000  24.29000
   .00000 100.00000 200.00000
 10.50000  10.30000  10.10000
 70.00000  70.00000  70.00000
  4.10000   5.22504   5.76969   4.10000   5.22504   5.76969   4.10000   5.22504
  5.76969   4.10000   5.22504   5.76969
  9.44880  10.26800  31.90000    .02821    .00000
  5.00000   5.00000   0   0   0   0
EXCS TEMP 4 TWRS 1 ARRAY 135 DEG TO WINDZ/D                    X/D
EXCS HUMI 4 TWRS 1 ARRAY 135 DEG TO WINDZ/D                    X/D
EXCS LIQM 4 TWRS 1 ARRAY 135 DEG TO WINDZ/D                    X/D
CASE (4)  5 TOWERS IN ROUND ARRAY
    5 100  30  30  11
    0   0   0   3  10   0   0   1   1   1   1
   .00000   5.00000  10.00000  15.00000  20.00000
  10.00000    .00000  20.00000   2.00000  12.00000
   .00000 100.00000 200.00000
 10.50000  10.30000  10.10000
 70.00000  70.00000  70.00000
  4.10000   5.22504   5.76969   4.10000   5.22504   5.76969   4.10000   5.22504
  5.76969   4.10000   5.22504   5.76969   4.10000   5.22504   5.76969
  9.44880  10.26800  31.90000    .02821    .00000
  5.00000   5.00000   0   0   0   0
EXCS TEMP 5 TWRS IN ROUND ARRAY          Z/D                   X/D
EXCS HUMI 5 TWRS IN ROUND ARRAY          Z/D                   X/D
EXCS LIQM 5 TWRS IN ROUND ARRAY          Z/D                   X/D
```

Table 4.2 Input Data Cards for Three Cases of Fan's (1967) Experiments with F = 20, K = 8; F = 40, K = 8; and F = 80, K = 16

```
 CASE (1)  60(D)  F=20  K=8

    1 350   1   1   1
    0   0   0   2   1   0   0   0   0   0   0
     .0
     .0
     .00000 -50.00000
   31.87000  31.87000
     .00000    .00000
     .13700    .13700
     .00760  -1.10000  20.00000    .00000    .00000


 CASE (2)  60(G)  F=40  K=8

    1 350   1   1   1
    0   0   0   2   1   0   0   0   0   0   0
     .0
     .0
     .00000 -50.00000
   26.57000  26.57000
     .00000    .00000
     .20400    .20400
     .00760  -1.63000  20.00000    .00000    .00000


 CASE (3)  60(J)  F=80  K=16

    1 350   1   1   1
    0   0   0   2   1   0   0   0   0   0   0
     .0
     .0
     .00000 -50.00000
   23.31000  23.31000
     .00000    .00000
     .14600    .14600
     .00760  -2.32000  20.00000    .00000    .00000
```

Table 4.3 Input Data Cards for Chan et al.'s (1974) Experiment with F = 4, K = 1.02

```
Case (1) 6 Towers in One Array 90 Degrees to Wind F=4, K=1.02
  6 100   21  17  11
  0   0    1   2   0   0   1  1   0   0  1
    .00000      .00000     .00000    .00000    .00000    .00000
    .00000      .06501     .13003    .19504    .26006    .32507
    .00000   900.00000
  25.00000    25.00000
    .00000      .00000
    .37621      .37621     .37621    .37621    .37621    .37621    .37621    .37621
    .37621      .37621     .37621    .37621
    .05690      .38374   30.00000    .00000    .00000
    .50000      .50000    1.00000   3.00000
   6.31250     5.06250    0   0   0   0
EXCS TEMP 6 TWRS 1 ARRAY 90 DEG TO WIND Z/D            X/D A3=0.3536 CD=1.5
```

Table 4.4 Input Data Cards for TVA (1968, TVA-11, single tower) Field Data in a Stable Atmospheric Condition ($\partial\theta/\partial z$=0.59°K/100 m)

CASE (1) 100% EXIT HUMI & 100% AMB HUMI

```
    1 300   1   1   1
    0   0   0   8   1   0   0   0   0   0   0
   .00000
   .00000
   .00000 100.00000 150.00000 200.00000 250.00000 300.00000 350.00000 400.00000
 20.00000  20.16000  20.24000  20.32000  20.40000  20.48000  20.56000  20.64000
100.00000 100.00000 100.00000 100.00000 100.00000 100.00000 100.00000 100.00000
  4.10000   4.10000   4.10000   4.70000   5.30000   5.90000   6.50000   7.10000
  7.90000  17.10000 139.00000    .67883    .00000
```

CASE (2) 100% EXIT HUMI & 70% AMB HUMI

```
    1 300   1   1   1
    0   0   0   8   1   0   0   0   0   0   0
   .00000
   .00000
   .00000 100.00000 150.00000 200.00000 250.00000 300.00000 350.00000 400.00000
 20.00000  19.61000  19.42000  19.23000  19.04000  18.84000  18.65000  18.46000
 70.00000  70.00000  70.00000  70.00000  70.00000  70.00000  70.00000  70.00000
  4.10000   4.10000   4.10000   4.70000   5.30000   5.90000   6.50000   7.10000
  7.90000  17.10000 139.00000    .67883    .00000
```

CASE (3) 100% EXIT HUMI & 0% AMB HUMI

```
    1 300   1   1   1
    0   0   0   8   1   0   0   0   0   0   0
   .00000
   .00000
   .00000 100.00000 150.00000 200.00000 250.00000 300.00000 350.00000 400.00000
 20.00000  19.61000  19.42000  19.23000  19.04000  18.84000  18.65000  18.46000
   .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  4.10000   4.10000   4.10000   4.70000   5.30000   5.90000   6.50000   7.10000
  7.90000  17.10000 139.00000    .67883    .00000
```

CASE (4) 0% EXIT HUMI & 0% AMB HUMI

```
    1 300   1   1   1
    0   0   0   8   1   0   0   0   0   0   0
   .00000
   .00000
   .00000 100.00000 150.00000 200.00000 250.00000 300.00000 350.00000 400.00000
 20.00000  19.61000  19.42000  19.23000  19.04000  18.84000  18.65000  18.46000
   .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  4.10000   4.10000   4.10000   4.70000   5.30000   5.90000   6.50000   7.10000
  7.90000  17.10000 139.00000    .00000    .00000
```

Table 4.5 Input Data Cards for TVA (1968, TVA-14, two towers) Field Data in an Atmosphere with an Inversion ($\partial\theta/\partial z$=1.42°K/100 m)

```
CASE (1)  100% EXIT HUMI & 100% AMB HUMI
    2 300   1   1   1
    0   0   0   6   1   0   1   0   0   0   0
   .00000  29.06000
   .00000  54.65000
   .00000  50.00000 100.00000 150.00000 200.00000 250.00000
  7.00000   7.43000   7.86000   8.29000   8.72000   9.15000
100.00000 100.00000 100.00000 100.00000 100.00000 100.00000
  8.60000   8.80000   9.10000  10.50000  11.60000  12.60000   8.60000   8.80000
  9.10000  10.50000  11.60000  12.60000
  7.90000  20.20000 149.00000    .73951    .00000

CASE (2)  100% EXIT HUMI &  70% AMB HUMI
    2 300   1   1   1
    0   0   0   6   1   0   1   0   0   0   0
   .00000  29.06000
   .00000  54.65000
   .00000  50.00000 100.00000 150.00000 200.00000 250.00000
  7.00000   7.22000   7.44000   7.67000   7.89000   8.11000
 70.00000  70.00000  70.00000  70.00000  70.00000  70.00000
  8.60000   8.80000   9.10000  10.50000  11.60000  12.60000   8.60000   8.80000
  9.10000  10.50000  11.60000  12.60000
  7.90000  20.20000 149.00000    .73951    .00000

CASE (3)  100% EXIT HUMI &   0% AMB HUMI
    2 300   1   1   1
    0   0   0   6   1   0   1   0   0   0   0
   .00000  29.06000
   .00000  54.65000
   .00000  50.00000 100.00000 150.00000 200.00000 250.00000
  7.00000   7.22000   7.44000   7.67000   7.89000   8.11000
   .00000    .00000    .00000    .00000    .00000    .00000
  8.60000   8.80000   9.10000  10.50000  11.60000  12.60000   8.60000   8.80000
  9.10000  10.50000  11.60000  12.60000
  7.90000  20.20000 149.00000    .73951    .00000

CASE (4)    0% EXIT HUMI &   0% AMB HUMI
    2 300   1   1   1
    0   0   0   6   1   0   1       0   0   0
   .00000  29.06000
   .00000  54.65000
   .00000  50.00000 100.00000 150.00000 200.00000 250.00000
  7.00000   7.22000   7.44000   7.67000   7.89000   8.11000
   .00000    .00000    .00000    .00000    .00000    .00000
  8.60000   8.80000   9.10000  10.50000  11.60000  12.60000   8.60000   8.80000
  9.10000  10.50000  11.60000  12.60000
  7.90000  20.20000 149.00000    .00000    .00000
```

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

In this study, a mathematical model and corresponding computer program have been developed for the prediction of plume behavior from multiple cooling towers. Some comparisons between the predictions based on the present model and the measured results from laboratories and the field are made in order to test the model. The following conclusions and recommendations are made based on this study.

(1) The model is developed for arbitrary vertical profiles of ambient temperature, humidity, wind velocity, and arbitrary tower arrangement. The velocity defect for the downstream towers due to the effect of the upstream towers and plumes can be included by specifying different ambient velocity profiles for each plume. A general expression for the velocity defect of the downstream towers might be developed in the future.

(2) The temperature range for which this model is valid is -50°C to 140°C, because of the accuracy associated with the calculation of the saturation humidity.

(3) A set of suggested values of entrainment and drag coefficients have been incorporated in the computer program. Because of the rapid merging and usually rapid bending over of the plumes, the coefficients a_3, α_s and C_d are the most important ones. Better estimates of their values are needed such as by further experimental study or field program.

(4) The merging criteria and processes (defined in this model by equations (2.38) (2.39) and (2.40)) could also be improved when further

research results on plume interaction are available.

(5) The blockage and recirculation effects in the wake zone of the towers and plumes have not been incorporated in the present model. Future effort could be made to include these effects.

(6) Based on comparisons between model and laboratory results (Fan, and Chan et al.), good predictions of dry plume behavior can be obtained. In order to verify the model for actual cooling tower plumes, a more complete set of experimental data (including the plume width, trajectory, dilution and detailed ambient profiles of temperature, humidity and wind velocity) are required. Therefore, a complete set of field measurement are strongly recommended for validation of the model.

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APPENDIX A

COMPUTER PROGRAM

The computer program based on the model and listed in Appendix C was tested on an IBM 370/158. The detailed input and output information are listed in this Appendix. The input ambient wind velocity profiles (AU(NP,MG)) for each tower are designed to allow consideration of the velocity defect in the wake of upstream towers (i.e., the tower array parallel to the ambient wind direction). In addition, some suggested input values are listed below for reference:

NS = 300

NX = 40

NY = 40

NCONT = 11

IX(3) = IX(6) = IX(11) =0

In this Appendix, the input sequence as well as the input and output variables are tabulated, explained and related to the symbols used in the text of this report.

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INPUT SEQUENCE

Symbol	Parameter	Format	Subroutine
NP,NS,NX,NY,NCONT		5I4	CTPS
(IX(I),I=1,11)		11I4	MTP
(CX(I),I=1,NP)		8F10.5	MTP
(CY(I),I=1,NP)		8F10.5	MTP
(AZ(I),I=1,MG)		8F10.5	MTP
(AT(I),I=1,MG)		8F10.5	MTP
(AH(I),I=1,MG)		8F10.5	MTP
((AU(I,J),J=1,MG),I=1,NP)		8F10.5	MTP
DI(1),UO(1), TO(1),HO(1),WO(1)	IX(1)=0+	8F10.5	MTP
(DI(I),I=1,NP)	IX(1)=1*	8F10.5	MTP
(UO(I),I=1,NP)	IX(1)=1*	8F10.5	MTP
(TO(I),I=1,NP)	IX(1)=1*	8F10.5	MTP
(HO(I),I=1,NP)	IX(1)=1*	8F10.5	MTP
(WO(I),I=1,NP)	IX(1)=1*	8F10.5	MTP
A1,A2,A3,A4,CD,TURBF	IX(2)=1*	8F10.5	MTP
DX,DZ,XO,ZO	IX(3)=1*	4F10.5	OUTPUT
WIDTH, HITE,MORE,NOMAP,ICENT NOTICK	IX(11)=1*	2F10.5 4I4	OUTPUT
(HEDN(k),k=1,10),(LABY(L),L=1,5),(LABX(M),M=1,5)	IX(8)=1*	20A4	OUTPUT
(HEDN(k),k=1,10),(LABY(L),L=1,5),(LABX(M),M=1,5)	IX(9)=1*	20A4	OUTPUT
(HEDN(k),k=1,10),(LABY(L),L=1,5),(LABX(M),M=1,5)	IX(10)=1*	20A4	OUTPUT

+ Skip card if IX(1)=1

* Skip card if the corresponding IX(I)=0, (I=1,2,3,11,8,9,10)

EXPLANATION OF THE INPUT SYMBOLS

In Program	In Text	Remarks
NP		Total number of towers
NS		Desired number of calculation steps
NX, NY [CONTA(NX,NY)]		Horizontal and vertical grid sizes, respectively (for contour plot)
NCONT [CONTB(NCONT)]		Desired contour levels for plotting
IX(1)		IX(1)=0 Same exit conditions of all the plumes (Input one card only)
		IX(1)=1 Different exit conditions of the plumes
IX(2)		IX(2)=0 No input card of entrainment and drag coefficients is needed
		IX(2)=1 Input the desired entrainment and drag coefficients
IX(3)		IX(3)=0 No input card of DX, DZ, XO and ZO is needed
		IX(3)=1 Input the desired values of DX, DZ, XO and ZO
		IX(3)=-1 No plot needed
IX(4)		MG Number of vertical levels for ambient conditions
IX(5)		INRPR Interval of detailed printout for plume 1
IX(6)		IPNT=0 For contour plot (always use IPNT=0)
IX(7)		LC=0 For cluster array (round array) of towers
		LC=1 For line or random array of towers
IX(8)		IX(8)=0 No contour map plotted for plume excess temperature
		IX(8)=1 Contour map plotted for plume excess temperature
IX(9)		IX(9)=0 No contour map plotted for plume excess humidity
		IX(9)=1 Contour map plotted for plume excess humidity
IX(10)		IX(10)=0 No contour map plotted for plume excess liquid moisture
		IX(10)=1 Contour map plotted for plume excess liquid moisture
IX(11)		IX(11)=0 No input card of WIDTH, HITE, MORE, NOMAP, ICENT, and NOTICK is needed
		IX(11)=1 Input the desired values of WIDTH, HITE, MORE, NOMAP, ICENT and NOTICK

In Program	In Text	Remarks
CX(NP)	x	x-coordinates of towers (in m)
CY(NP)	y	y-coordinates of towers (in m)
AZ(MG)	z	Ambient levels (in m)
AT(MG)	ta	Ambient temperature profile corresponding to AZ(I) (in °C)
AH(MG)	q_a	Ambient relative humidty profile corresponding to AZ(I) (in percentage of the saturation humidity)
AU(NP,MG)	U_a	Ambient wind velocity profile corresponding to AZ(I) for each tower (in m/sec)
DI(NP)	D_o	Diameter of each tower (in m)
UO(NP)	U_o	Exit velocity of each plume (in m/sec)
TO(NP)	t_o	Exit temperature of each plume (in °C)
HO(NP)	q_o	Exit specific humidity of each plume (in kg/kg)
WO(NP)	σ_o	Exit liquid phase moisture of each plume (in kg/kg)
A1,A2,A3 and A4	a_1,a_2,a_3 and a_4	Entrainment coefficients (Default: A1=0.0806, A2=0.4775, A3=0.3536, A4=0.)
CD	C_d	Drag coefficient (Default: CD=1.5)
TURBF	U'_a	Intensity of ambient turbulent fluctuations (in percentage, decimal; Default: TURBF=0.)
DX,DZ		Increments of grid size in x and z directions, respectively (Normalized by the diameter of the first tower; Default:DX=0.5, DZ=0.5)
XO,ZO		Location of the center of the top of the first tower in the grid (Normalized by the diameter of the first tower; Default:XO=1, ZO=2.)
WIDTH,HITE		Width and height of contour map, respectively (Inches; Default: 8", 8")
MORE		MORE=1 Do not finish off the map (Default: MORE=0)
NOMAP		NOMAP=1 Do not force grid to be square (Default:NOMAP=0)
ICENT		ICENT=1 Do not center the title (Default: ICENT=0)
NOTICK		NOCITK=1 Do not draw tick marks (Default: NOTICK=0)

In Program	In Text	Remarks
HEDN(10)		40 characters to plot as title on top (Default: Blank)
LABY(5)		20 characters to plot as label on vertical left (Default: Blank)
LABX(5)		20 characters to plot as label on horizontal bottom (Default: Blank)

EXPLANATIONS OF THE OUTPUT SYMBOLS

In Program	In Text	Remarks
EXIT,COEF,TWLC,AMBL, INPR,IPNT,LC,ETPL, EHPL,EMPL,COPL		Correspond to IX(I) to IX(11) respectively
A1,A2,A3,A4,CD, TURBF	a_1, a_2, a_3, a_4, C_d, U_a'	Same as input symbols
NTHP		The N^{th} plume
CX,CY [(CX(I),CY(I)]		Same as input symbols
DIA,VELO,TEMP,HUMI, LPMO [DI(I),UO(I), HO(I)WO(I)]	D_o, U_o, t_o, q_o, σ_o	Tower diameter, exit values of plume velocity, temperature, specific humidity and liquid phase moisture, respectively
NSTEP*		The N^{th} step of calculation referred to each tower
X,Y,Z [PX(NP,NS),PY(NP,NS), PZ(NP,NS)]	x,y,z	The horizontal, lateral and vertical coordinates of plume center
PTEMP,PHUMI,PLQDMOIST [PT(NP,NS),PH(NP,NS), PW(NP,NS)]	t_p, q_p, σ_p	Plume temperature, specific humidity and liquid phase moisture respectively
EXCEST, EXCESH [PET(NP,NS),PEH (NP,NS)]	Δt, Δq	Excess plume temperature and specific humidity
PCROSEC [BXZ(I)]	HT/2	Half height of plume cross-section
SLOTLEN[A(I)]	A	Finite length of slot jet of the merged plume
PANGLE[PCOS(NP,NS) PSIN(NP,NS)]	θ	The angle between the tangent of plume trajectory and the horizontal line
DILUTN [PDIL(NP,NS)]	Q/Q_o	Plume dilution
PVELO [PU(NP,NS)]	U_p	Plume velocity

* NSTEP refers to the number of calculation step of plume 1 when each plume first appeared

APPENDIX B

EXPLANATION OF THE IMPORTANT SYMBOLS IN THE PROGRAM MTP

In Program	In Text		Remarks
PX(NP,NS)	x		*
PY(NP,NS)	y		*
PZ(NP,NS)	z		*
PS(NP,NS)	s		*
PCOS(NP,NS)	$\cos\theta$		*
PSIN(NP,NS)	$\sin\theta$		*
PQ(NP,NS)	Q		*
PMX(NP,NS)	M_x		*
PMZ(NP,NS)	M_z		*
PF(NP,NS)	F		*
PG(NP,NS)	G		*
PH(NP,NS)	H		*
PW(NP,NS)	W		*
PT(NP,NS)	T		*
PET(NP,NS)	$t_p - t_a$		Excess temperature
PEH(NP,NS)	$q_p - q_a$		Excess humidity
PAN(NP,NS)	θ		*
PU(NP,NS)	U		Net plume velocity
PENT(NP,NS)	E		*
PA(NP,NS)	A		*
PB(NP,NS)	b or (B1+B2)/2		Average plume width
PC(NP,NS)	BXZ		*
PDIL(NP,NS)	Q/Q_o		Plume dilution
CONTA(NX,NY)			Normalized PET,PEH & PW (or PEW)
CONTB(NCONT)			Contour levels
IND(I)			Indication of the status of each plume
		IND(I)=5	Plume which has not been started
		IND(I)=1	Single plume
		IND(I)=2	Merged plume
		IND(I)=3	All plumes are merged
IS(I)			Beginning step number for each plume
MP(I)			Merged plume pair
MS(I)			Merged plume step numbers associated with MP(I)
A(I)	A		*
B1(I)	B1		*
B2(I)	B2		*
BXZ(I)	BXZ		*
BY(I)	BY		*
PMCOS(I)	$\cos\phi$		*
PMSIN(I)	$\sin\phi$		*
DW(I)	2·BY		*
NBV(I)			Beginning step number for visible plume
NEV(I)			Ending step number for visible plume
PAI	π		3.1415926
GRA	g		*
A1	a_1		*
A2	a_2		*
A3	a_3		*
A4	a_4		*

In Program	In Text		Remarks
CD	C_d		*
TURBF	U_a'		*
UC	U_p		*
B			Plume width
TP	t_p		*
HP	q_p		*
WP	σ_p		*
ET	$t_p - t_a$		Excess temperature
EH	$q_p - q_a$		Excess humidity
MG			Elevation level
CFRL	Fr_{LC}		*
ALV	L_v		*
CPA	C_{pa}		*
ANG	θ		*
ITHP			i^{th} plume
ENTRAN	E		*
IQ		<3	All the plumes have not been completely merged
		=3	All the plumes have merged
		>3	All the plumes have merged and become a round plume again
IL			Number of merged pairs
IK			Plume step number
KE(I)			Ending step number of each plume
Y(I)	Y(1)=Q		*
	Y(2)=Mcosθ		*
	Y(3)=Msinθ		*
	Y(4)=G		*
	Y(5)=F		*
	Y(6)=x		*
	Y(7)=z		*
YP(I)			Derivatives of Y(I) with respect to s
YR1(I),YR2(I), & YS(I)			Y(I) associated with the two half round plumes and the central slot plume for the merged plume
YR1P(I),YR2P(I), & YSP(I)			YP(I) associated with the two half round plumes and the central slot plume for the merged plume

* Refer to "List of Symbols"

APPENDIX C

LISTING OF PROGRAM

```
FORTRAN IV G LEVEL 20.7 VS              MAIN                    DATE =     6/07/77      14:32:

0001                  DIMENSION IA(2),I(26)
                    C     NP=NUMBER OF PLUME,NS=NUMBER OF CALCULATION STEP, NX,NY=DESIRED
                    C     GRID OF CONTOUR PLOT, NCONT=DESIRED CONTOUR LEVELS
0002                3 READ(5,2,END=9) NP,NS,NX,NY,NCONT
0003                2 FORMAT(5I4)
0004                  N4=MAXO(NX,NY)
0005                  NTOTAL=NP*NS
0006                  IA(2)=NTOTAL*23+NX*NY+NCONT+N4
0007                  CALL GETVEC(IA)
0008                  I(1)=IA(3)
0009                  DO 1 J=2,24
0010                1 I(J)=I(J-1)+NTOTAL
0011                  I(25)=I(24)+NX*NY
0012                  I(26)=I(25)+NCONT
0013                  CALL MTP(IA(I(1)),IA(I(2)),IA(I(3)),IA(I(4)),IA(I(5)),IA(I(6)),
                     1IA(I(7)),IA(I(8)),IA(I(9)),IA(I(10)),IA(I(11)),IA(I(12)),IA(I(13))
                     2,IA(I(14)),IA(I(15)),IA(I(16)),IA(I(17)),IA(I(18)),IA(I(19)),
                     3IA(I(20)),IA(I(21)),IA(I(22)),IA(I(23)),IA(I(24)),IA(I(25)),
                     4IA(I(26)),NP,NS,NX,NY,NCONT,N4)
0014                  CALL FREEUP(IA)
0015                  GO TO 3
0016                9 STOP
0017                  END
```

```
FORTRAN IV G LEVEL 20.7 VS                MTP                    DATE =     6/07/77      14:32

0001                  SUBROUTINE MTP(PX,PZ,PQ,PMX,PMZ,PG,PF,PCOS,PSIN,PENT,PU,PS,PB,PA,
                     1PT,PET,PH,PEH,PW,PAN,PDIL,PY,PC,CONTA,CONTB,CONTC,NP,NS,NX,NY,
                     2NCONT,N4)
0002                  EXTERNAL DERIVE,DERIVS,DERIVF
0003                  DOUBLE PRECISION AQ,BQ,CQ,DQ
0004                  COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
                     1       /STORE2/MP(30),MS(30),IIP(30)
                     2       /STORE3/AH(30),AT(30),AZ(30),AHG(30),ATG(30),AU(30,30),
                     A              AUG(30,30)
                     3       /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
                     4              PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
                     5       /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
                     6              MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
                     7       /CONST2/IL,NII,IK,NI,NIP1
                     8       /CONST3/AQ,BQ,CQ,DQ
                     9       /CONTUU/WIDTH,HITE,MORE,NOMAP,ICENT,NOTICK,HEDN(10),
                     *              LABY(5),LABX(5)
                     B       /STORE5/DI(30),UO(30),TO(30),HC(30),WO(30)
0005                  DIMENSION PX(NP,NS),PZ(NP,NS),PQ(NP,NS),PMX(NP,NS),PMZ(NP,NS),
                     1PB(NP,NS),PU(NP,NS),PF(NP,NS),PG(NP,NS),PCOS(NP,NS),PSIN(NP,NS),
                     2PENT(NP,NS),PH(NP,NS),PW(NP,NS),PEH(NP,NS),CX(30),CY(30),KE(30),
                     3PT(NP,NS),PS(NP,NS),PA(NP,NS),PET(NP,NS),PAN(NP,NS),PY(NP,NS),
                     4Y(8),YP(8),YS(8),YSP(8),YR1(8),YR1P(8),YR2(8),YR2P(8),PDIL(NP,NS
                     5CONTA(NX,NY),CONTB(NCONT),CONTC(N4),IX(12),MGPA2(30),MGST1(30),
                     6PC(NP,NS),LCHK(30),AHP(30)
                C     INITIALIZE STORAGES
0006                  CALL BLANK(PX,PZ,PQ,PMX,PMZ,PB,PU,PF,PG,PCOS,PSIN,PENT,PT,PS,PA,
                     1PET,PEH,PAN,PY,PDIL,PH,PW,PC,NP,NS,NX,NY,NCONT,N4,CONTA,CONTB,
                     2CONTC,MGPA2,MGST1,DX,DZ,XO,ZO,IPNT,KE,LCHK,AHP)
                C     INPUT CONTROL PARAMETERS
0007                  READ(5,2) (IX(I),I=1,11)
0008                  MG=IX(4)
0009                  INTPR=IX(5)
0010                  IPNT=IX(6)
0011                  LC=IX(7)
                C     INPUT TOWER CONFIGURATION
0012                  READ(5,1) (CX(I),I=1,NP)
0013                  READ(5,1) (CY(I),I=1,NP)
                C     INPUT AMBIENT CONDITIONS
0014                  READ(5,1) (AZ(I),I=1,MG)
0015                  READ(5,1) (AT(I),I=1,MG)
0016                  READ(5,1) (AHP(I),I=1,MG)
0017                  READ(5,1) ((AU(I,J),J=1,MG),I=1,NP)
0018                  IF(IX(1) .GT. 0) GO TO 34
                C     INPUT TOWER EXIT CONDITIONS;DI=DIA. UC=VELO., TO=TEMP., HO=HUMID
                C     WO=LIQUID PHASE MOISTURE
0019                  READ(5,1)DI(1),UC(1),TO(1),HC(1),WO(1)
0020                  DO 24 I=2,NP
0021                  DI(I)=DI(1)
0022                  UC(I)=UC(1)
0023                  TO(I)=TO(1)
0024                  HC(I)=HC(1)
0025               24 WO(I)=WO(1)
0026                  GO TO 35
0027               34 READ(5,1) (DI(I),I=1,NP)
0028                  READ(5,1) (UO(I),I=1,NP)
```

```
FORTRAN IV G LEVEL 20.7 VS                MTP                    DATE =     6/07/77      14:32

0029                READ(5,1) (TO(I),I=1,NP)
0030                READ(5,1) (HO(I),I=1,NP)
0031                READ(5,1) (WO(I),I=1,NP)
0032             35 IF(IX(2) .LE. 0) GO TO 32
                 C     INPUT COEFFICIENTS OF ENTRAINMENT AND DRAG ;TURBF=TURB. FLUCT.
                 C     TURBF=%(IN DECIMAL) OF AMBIENT WIND VELOCITY
0033                READ(5,1)A1,A2,A3,A4,CD,TURBF
0034                CFRL=A2/(0.116-A1)
0035              1 FORMAT(8F10.5)
0036              2 FORMAT(12I4)
0037             32 WRITE(6,555)
0038            555 FORMAT(1H1)
0039                WRITE(6,3)
0040              3 FORMAT(1X,'UNITS OF THE VARIABLES')
0041                WRITE(6,4)
0042              4 FORMAT(1X,'LENGTH:M,  TEMP:C,  MOISTURE:KG/KG,  VELO:M/SEC,  ANGL
                   1:DEG')
0043                WRITE(6,50)NP,NS,NX,NY,NCONT
0044                WRITE(6,49)
0045                WRITE(6,36)
0046                WRITE(6,48) (IX(J),J=1,11)
0047             50 FORMAT(1X,'NO. OF TOWERS=',I4,'  NO. OF CALCULATION STEPS=',I4,
                   1'  GRID SIZE (X,Y)=',I4,'  X',I4,'  CONTOUR LEVELS=',I4//)
0048             49 FORMAT(1X,'CONTROL PARAMETERS')
0049             36 FORMAT(' EXIT  COEF  TWLC  AMBL  INPR  IPNT  LC   ETPL  EHPL  '
                   1'EMPL  COPL')
0050             48 FORMAT(1X,11(I4,2X)//)
0051                WRITE(6,5)
0052              5 FORMAT(1X,'COEFFICIENTS OF ENTRAINMENT AND DRAG')
0053                WRITE(6,6)A1,A2,A3,A4,CD,TURBF
0054              6 FORMAT(1X,'A1=',F8.5,5X,'A2=',F8.5,5X,'A3=',F8.5,5X,'A4=',F8.5,5
                   1'CD=',F8.5,5X,'TURBF=',F8.5//)
0055                WRITE(6,7)
0056              7 FORMAT(1X,'AMBIENT PROFILES')
0057                WRITE(6,8)
0058              8 FORMAT(3X,'HEIGHT',7X,'TEMP',12X,'HUMIDITY',9X,'VELOCITY')
0059                DO 556 I=1,MG
0060                TK=AT(I)+273.16
0061                T=1.-373.16/TK
0062                EST=EXP((13.3185-(1.976+(0.6445+0.1229*T)*T)*T)*T)
0063                ES=0.622*1013.25*EST
0064                FSH=ES/(1013.25+ES)
0065            556 AH(I)=AHP(I)*0.01*FSH
0066                DO 9 I=1,MG
0067              9 WRITE(6,10)AZ(I),AT(I),AH(I),AHP(I),AU(1,I)
0068             10 FORMAT(1X,2(F10.5,2X),F10.6,1X,'(',F6.2,'%)',2X,F10.5)
0069                WRITE(6,11)
0070             11 FORMAT(/)
0071                WRITE(6,12)
0072             12 FORMAT(1X,'TOWER CONFIGURATION AND EXIT CONDITIONS')
0073                WRITE(6,18)
0074             18 FORMAT(2X,'NTHP',6X,'CX',8X,'CY',8X,'DIA',4X,'VELO',6X,'TEMP',9)
                   1'HUMI',9X,'LPMO')
0075                DO 17 I=1,NP
0076             17 WRITE(6,13)I,CX(I),CY(I),DI(I),UO(I),TO(I),HO(I),WO(I)
0077             13 FORMAT(1X,I5,3X,F7.2,3X,F7.2,3X,F6.2,3X,F6.2,3X,F8.3,3X,F12.8,3)
```

```
     1F12.8)
0078      WRITE(6,242)
      C   CALCULATION OF TEMPERATURE,HUMIDITY AND VELOCITY GRADIENTS
0079      MG1=MG-1
0080      DO 14 I=1,MG1
0081      II=I+1
0082      DV=AZ(II)-AZ(I)
0083      ATG(I)=(AT(II)-AT(I))/DV
0084   14 AHG(I)=(AH(II)-AH(I))/DV
0085      DO 47 J=1,NP
0086      DO 47 I=1,MG1
0087      II=I+1
0088      DV=AZ(II)-AZ(I)
0089   47 AUG(J,I)=(AU(J,II)-AU(J,I))/DV
0090      DO 148 I=1,NP
0091      DO2=DI(I)/2.
0092      BXZ(I)=DO2
0093      BY(I)=DO2
0094      B1(I)=DO2
0095  148 B2(I)=DO2
0096      WRITE(6,15)
0097   15 FORMAT(1X,'PLUME    1  APPEARS AT NSTEP=    1',//)
      C   SET INITIAL CONDITIONS
0098      TP=TO(1)
0099      ALV=FALV(TP)
0100      CALL SETIC(Y,ITHP,CX)
      C   INTEGRATION BY RUNGE-KUTTA METHOD
0101      L=0
0102      S=0.
0103      IKT=1
0104      DS=DI(ITHP)/20.
0105      GO TO 598
0106   86 IF(NIP1 .GT. NP) GO TO 19
      C   CHECK IF ANY NEW PLUME APPEARS
0107      CALL CHKNWP(PX,PZ,PQ,PMX,PMZ,PG,PF,PCOS,PSIN,PENT,PU,PS,PB,PA,PT,
     1PET,PH,PEH,PW,PAN,PY,PDIL,PC,CX,NP,NS,DERIVR,CY,KE)
0108   19 IF(NII-1)16,105,105
0109  357 IKT=IK+NOVIK(1)
0110      ITHP=1
0111      ALV=FALV(TP)
0112      DS=0.1*PB(1,IKT-1)
0113  598 CALL RUNGS(S,DS,7,Y,YP,L,DERIVR)
0114      B1(1)=B
0115      B2(1)=B
0116      BXZ(1)=B
0117      BY(1)=B
      C   SOLUTIONS FOR SINGLE PLUME
0118      CALL SOLUTN(PX,PY,PZ,PQ,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PCOS,PSIN
     1PT,PET,PH,PEH,PW,PAN,PDIL,PC,CY,Y,YP,S,ITHP,IKT,NP,NS)
0119      GO TO 78
      C   CHECK IF ANY NEW PLUME MERGING OCCURS
0120  105 CALL ALIGN(PX,PY,PZ,PW,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PC,PCOS,
     1PSIN,PT,PET,PH,PEH,PW,PAN,PDIL,CY,Y,YP,YS,YSP,YR1,YR1P,YR2,YR2P,
     2DERIVE,DERIVS,DERIVR,S,LC,NP,NS,KE)
0121      CALL PLMERG(PX,PY,PZ,PT,PET,PH,PEH,PW,PA,PB,PAN,PDIL,PCOS,PSIN,
     1CY,NP,NS,KE,MGPA2,MGST1,PC,LCHK,PU)
```

```
0122          16 DO 23 I=1,NI
0123             ITHP=I
0124             IKT=IK+NOVIK(I)-IS(I)+1
0125             IF(IND(I) .LT.1) GO TO 23
0126             DS=0.1*PB(I,IKT-1)
               C  RESET INITIAL CONDITIONS AND CALCULATE PLUME PROPERTIES FOR SINGLE
               C  AND MERGED PLUMES
0127             CALL RESETI(I,IKT,DS,S,NP,NS,CY,Y,YP,YS,YSP,YR1,YR1P,YR2,YR2P,
                1DERIVE,DERIVS,DERIVR,PX,PZ,PQ,PMX,PMZ,PG,PF,PCOS,PSIN,PENT,PU,PB,
                2PA,PT,PET,PEH,PW,LC)
               C  SOLUTIONS OF PLUMES INCLUDING SINGLE & MERGED PLUMES
0128             CALL SOLUTN(PX,PY,PZ,PQ,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PCOS,PSIN,
                1PT,PET,PH,PEH,PW,PAN,PDIL,PC,CY,Y,YP,S,I,IKT,NP,NS)
0129          23 CONTINUE
0130             IL=0
0131          78 DO 77 I=1,NP
0132             IF((IK+NOVIK(I)) .LT. NS) GO TO 77
0133             IND(I)=0
0134          77 CONTINUE
0135             DO 75 I=1,NP
0136             IF(IND(I) .GT. 0) GO TO 79
0137          75 CONTINUE
0138             GO TO 80
0139          79 IK=IK+1
0140             IF(IQ-3)86,16,397
0141          80 DO 81 I=1,NP
0142             IF(KE(I) .LE. 0) GO TO 82
0143             IF(LCHK(I) .LT. 1)GO TO 81
0144             KE(I)=KE(I)+1
0145             J=KE(I)
0146             K=MGPA2(I)
0147             L=MGSTI(I)+1
0148             PX(I,J)=PX(K,L)
0149             PZ(I,J)=PZ(K,L)
0150             PB(I,J)=PB(K,L)
0151             PC(I,J)=PC(K,L)
0152             PCOS(I,J)=PCOS(K,L)
0153             PSIN(I,J)=PSIN(K,L)
0154             PET(I,J)=PET(K,L)
0155             PEH(I,J)=PEH(K,L)
0156             PW(I,J)=PW(K,L)
0157             GO TO 81
0158          82 KE(I)=NS
0159          81 CONTINUE
0160             WRITE(6,808)
0161         808 FORMAT(1X,'RESULTS OF THE VISIBLE PLUMES')
0162             WRITE(6,225)
0163             CH=0.
0164             DO 807 I=1,NP
0165             KEN=KE(I)
0166             DO 803 J=1,KEN
0167             IF(PW(I,J).GT.0.)GO TO 802
0168             IF(NCV(I).EQ.0)GO TO 803
0169             NEV(I)=J
0170             NCV(I)=0
0171             CH=2.
```

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FORTRAN IV G LEVEL 20.7 VS              MTP                DATE =     6/07/77      14:32:

0172                WRITE(6,809)J,I,PX(I,J),PZ(I,J),PY(I,J),PT(I,J),PET(I,J),PH(I,J),
                   1PEH(I,J),PW(I,J),PB(I,J),PC(I,J),PA(I,J),PAN(I,J),PDIL(I,J),
                   2PU(I,J)
0173            809 FORMAT(1X,2(I5,1X),3(F8.2,1X),2(F7.2,1X),3(F8.5,1X),6(F7.2,1X),/)
0174                GO TO 803
0175            802 IF(NCV(I).NE.0)GO TO 803
0176                NBV(I)=J
0177                NCV(I)=1
0178                CH=1.
0179                WRITE(6,241)J,I,PX(I,J),PZ(I,J),PY(I,J),PT(I,J),PET(I,J),PH(I,J),
                   1PEH(I,J),PW(I,J),PB(I,J),PC(I,J),PA(I,J),PAN(I,J),PDIL(I,J),
                   2PU(I,J)
0180            241 FORMAT(1X,2(I5,1X),3(F8.2,1X),2(F7.2,1X),3(F8.5,1X),6(F7.2,1X))
0181            803 CONTINUE
0182                IF(CH-1.) 804,805,807
0183            804 WRITE(6,233)I
0184            233 FORMAT(1X,'NO VISIBLE PART OF PLUME FOR PLUME',I4/)
0185                GO TO 807
0186            805 WRITE(6,243)I,J
0187            243 FORMAT(1X,'PLUME',I4,' STILL VISIBLE AT THE TERMINATION STEP',I4/
0188            807 CONTINUE
0189                WRITE(6,242)
0190            242 FORMAT(//)
0191                WRITE(6,224)
0192            224 FORMAT(1X,'RESULTS AT THE LAST STEP OF CALCULATION')
0193                WRITE(6,225)
0194            225 FORMAT(1X,'NSTEP   NTHP     X          Z          Y       PTEMP   EXCEST
                   1,'  PHUMI    EXCESH PLODMOIST PAVHFWD PCROSEC SLOTLEN  PANGLE  ',
                   2'DILUTN  PVELO')
0195                NTHP=1
0196                WRITE(6,226)NS,NTHP,PX(1,NS),PZ(1,NS),PY(1,NS),PT(1,NS),PET(1,NS)
                   1PH(1,NS),PEH(1,NS),PW(1,NS),PB(1,NS),PC(1,NS),PA(1,NS),PAN(1,NS),
                   2PDIL(1,NS),PU(1,NS)
0197            226 FORMAT(1X,2(I5,1X),3(F8.2,1X),2(F7.2,1X),3(F8.5,1X),6(F7.2,1X),//
0198                CALL CUTRUT(PX,PY,PZ,PT,PET,PH,PEH,PW,PA,PC,PAN,PDIL,PSIN,PCOS,
                   1CONTA,CONTB,CONTC,KE,INTPR,IPNT,NX,NY,NCONT,N4,NP,NS,IX,DX,DZ,XO,
                   2ZC,PB,PS,PU)
0199                RETURN
0200                END
```

```
FORTRAN IV G LEVEL 20.7 VS              BLANK                DATE =     6/07/77      14:32:

0001            SUBROUTINE BLANK(PX,PZ,PQ,PMX,PMZ,PB,PU,PF,PG,PCOS,PSIN,PENT,
               1PT,PS,PA,PET,PEH,PAN,PY,PDIL,PH,PW,PC,NP,NS,NX,NY,NCONT,N4,CONTA,
               2CONTB,CONTC,MGPA2,MGST1,DX,DZ,XO,ZO,IPNT,KE,LCHK,AHP)
0002            DOUBLE PRECISION AQ,BQ,CQ,DQ
0003            COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
               1       /STORE2/MP(30),MS(30),IIP(30)
               2       /STORE3/AH(30),AT(30),AZ(30),AHG(30),ATG(30),AU(30,30),
               A              AUG(30,30)
               3       /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
               4              PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
               5       /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
               6              MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
               7       /CONST2/IL,NII,IK,NI,NIP1
               8       /STORE5/DI(30),UO(30),TO(30),HC(30),WO(30)
               9       /CONST3/AQ,BQ,CQ,DQ
0004            DIMENSION PX(NP,NS),PZ(NP,NS),PQ(NP,NS),PMX(NP,NS),PMZ(NP,NS),
               1PB(NP,NS),PU(NP,NS),PF(NP,NS),PG(NP,NS),PCOS(NP,NS),PSIN(NP,NS),
               2PENT(NP,NS),PT(NP,NS),PS(NP,NS),PA(NP,NS),PET(NP,NS),PEH(NP,NS),
               3PAN(NP,NS),PH(NP,NS),PW(NP,NS),PY(NP,NS),PDIL(NP,NS),CONTA(NX,NY),
               4CONTB(NCONT),CONTC(N4),MGPA2(30),MGST1(30),PC(NP,NS),KE(30),
               5LCHK(30),AHP(30)
0005            DO 4 I=1,NP
0006            MGPA2(I)=0
0007            MGST1(I)=0
0008            IS(I)=0
0009            LCHK(I)=0
0010            A(I)=0.
0011            NBV(I)=0
0012            NEV(I)=0
0013            NCV(I)=0
0014            DW(I)=0.
0015            PMSIN(I)=0.
0016            PMCOS(I)=0.
0017            IND(I)=5
0018            MP(I)=0
0019            MS(I)=0
0020            IIP(I)=0
0021            INDT(I)=0
0022          4 NOVIK(I)=0
0023            DO 1 I=1,NP
0024            DO 1 J=1,NS
0025            PX(I,J)=0.
0026            PZ(I,J)=0.
0027            PQ(I,J)=0.
0028            PMX(I,J)=0.
0029            PMZ(I,J)=0.
0030            PF(I,J)=0.
0031            PG(I,J)=0.
0032            PC(I,J)=0.
0033            PB(I,J)=0.
0034            PCOS(I,J)=0.
0035            PSIN(I,J)=0.
0036            PU(I,J)=0.
0037            PENT(I,J)=0.
0038            PET(I,J)=0.
0039            PEH(I,J)=0.
```

```
0040            PT(I,J)=0.
0041            PS(I,J)=0.
0042            PA(I,J)=0.
0043            PH(I,J)=0.
0044            PY(I,J)=0.
0045            PAN(I,J)=0.
0046            PDIL(I,J)=C.
0047          1 PW(I,J)=0.
0048            DO 2 I=1,NX
0049            DO 2 J=1,NY
0050          2 CCNTA(I,J)=0.
0051            DO 3 I=1,NCONT
0052          3 CONTB(I)=0.
0053            DO 5 I=1,N4
0054          5 CONTC(I)=0.
0055            DO 6 I=1,30
0056            DO 6 J=1,30
0057            AUG(I,J)=0.
0058          6 AU(I,J)=0.
0059            DO 7 I=1,30
0060            KE(I)=0
0061            AZ(I)=0.
0062            AT(I)=0.
0063            AHP(I)=0.
0064            AH(I)=0.
0065            ATG(I)=0.
0066          7 AHG(I)=0.
0067            AQ=0.000009153132
0068            BQ=0.0002112502
0069            CQ=0.003660244
0070            DQ=0.009494118
0071            CPA=1.005
0072            PAI=3.14159265
0073            GRA=9.8066
0074            A1=0.0806
0075            A2=0.6753
0076            A3=0.3536
0077            A4=0.
0078            CD=1.5
0079            TURBF=0.
0080            DX=0.5
0081            DZ=0.5
0082            XO=1.
0083            ZO=2.
0084            IPNT=0
0085            CFRL=A2/(0.116-A1)
0086            IL=0
0087            NII=0
0088            IK=1
0089            IQ=1
0090            NI=1
0091            NIP1=2
0092            ITHP=1
0093            IND(1)=1
0094            IS(1)=1
0095            RETURN
0096            END
```

```
FORTRAN IV G LEVEL 20.7 VS              FALV                    DATE =     6/07/77      14:3
0001                  FUNCTION FALV(TC)
                    C TO DETERMINE LATEN HEAT ALV
0002                  IF(TC .LT. 0.) GO TO 1
0003                  FALV=(597.31-0.57*TC)*4.1868
0004                  GO TO 2
0005                1 FALV=(677.01+0.622*TC)*4.1868
0006                2 RETURN
0007                  END
```

```
FORTRAN IV G LEVEL 20.7 VS              SETIC                DATE =     6/07/77      14:
0001                  SUBROUTINE SETIC(Y,I,CX)
0002                  COMMON /CONSI1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
                     1                MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
                     2          /STORE3/AH(30),AT(30),AZ(30),AHG(30),ATG(30),AU(30,30),
                     *                AUG(30,30)
                     3          /STORE5/DI(30),UO(30),TO(30),HO(30),WO(30)
0003                  DIMENSION Y(8),CX(30)
0004                  Y(1)=PAI*DI(I)*DI(I)*ABS(UO(I))/4.
0005                  Y(2)=0.
0006                  Y(3)=Y(1)*UO(I)
0007                  Y(4)=Y(1)*(TO(I)-AT(1)-WO(I)*ALV/CPA)
0008                  Y(5)=Y(1)*(HO(I)-AH(1)+WO(I))
0009                  Y(6)=CX(I)
0010                  Y(7)=0.
0011                  RETURN
0012                  END
```

```
FORTRAN IV G LEVEL 20.7 VS              RUNGS              DATE =     6/07/77      14:32

0001                  SUBROUTINE RUNGS(X,H,N,Y,YPRIME,INDEX,DERIV)
0002                  DIMENSION Y(8),YPRIME(8),Z(8),W1(8),W2(8),W3(8),W4(8)
                C     RUNGS-RUNGE-KUTTA SOLUTION OF SET OF FIRST ORDER O.D.E. FORTRAN I
                C     DIMENSIONS MUST BE SET FOR EACH PROGRAM
                C     X    INDEPENDENT VARIABLE
                C     H    INCREMENT DELTA X,MAY BE CHANGED IN VALUE
                C     N    NUMBER OF EQUATIONS
                C     Y    DEPENDENT VARIABLE BLOCK    ONE DIMENSIONAL ARRAY
                C     YPRIME    DERIVATIVE BLOCK     ONE DIMENSIONAL ARRAY
                C     THE PROGRAMMER MUST SUPPLY INITIAL VALUES OF Y(1) TO Y(N)
                C     INDEX    IS A VARIABLE WHICH SHOULD BE SET TO ZERO BEFORE EACH
                C     INITIAL ENTRY TO THE SUBROUTINE, I.E., TO SOLVE A DIFFERENT
                C     SET OF EQUATIONS OR TO START WITH NEW INITIAL CONDITIONS.
                C     THE PROGRAMMER MUST WRITE A SUBROUTINE CALLED DERIVE WHICH
                C     COMPUTES THE DERIVATIVES AND STORES THEM
                C     THE ARGUMENT LIST IS SUBROUTINE DERIVE(X,N,Y,YPRIME)
0003                  IF(INDEX) 5,5,1
0004                1 DO 2 I=1,N
0005                  W1(I)=H*YPRIME(I)
0006                2 Z(I)=Y(I)+(W1(I)*.5)
0007                  A=X+0.5*H
0008                  CALL DERIV(A,N,Z,YPRIME)
0009                  DO 3 I=1,N
0010                  W2(I)=H*YPRIME(I)
0011                3 Z(I)=Y(I)+.5*W2(I)
0012                  A=X+0.5*H
0013                  CALL DERIV(A,N,Z,YPRIME)
0014                  DO 4 I=1,N
0015                  W3(I)=H*YPRIME(I)
0016                4 Z(I)=Y(I)+W3(I)
0017                  A=X+H
0018                  CALL DERIV(A,N,Z,YPRIME)
0019                  DO 7 I=1,N
0020                  W4(I)=H*YPRIME(I)
0021                7 Y(I)=Y(I)+(((2.*(W2(I)+W3(I)))+W1(I)+W4(I))/6.)
0022                  X=X+H
0023                  CALL DERIV(X,N,Y,YPRIME)
0024                  GO TO 6
0025                5 CALL DERIV(X,N,Y,YPRIME)
0026                  INDEX=1
0027                6 RETURN
0028                  END
```

```
FORTRAN IV G LEVEL 20.7 VS              DERIVR              DATE =     6/07/77      15:27:

0001                  SUBROUTINE DERIVR(S,N,Y,YP)
0002                  DOUBLE PRECISION AQ,BQ,CQ,DQ
0003                  COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
                     1       /STORE3/AH(30),AT(30),AZ(30),AHG(30),ATG(30),AU(30,30),
                     A              AUG(30,30)
                     3       /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
                     4              MG,MG1,CFRL,ALV,CPA,ANG,IC,ITHP,ENTRAN
                     5       /CONST3/AQ,BQ,CQ,DQ
                     6       /STORE5/DI(30),UO(30),TO(30),HO(30),WO(30)
0004                  DIMENSION Y(8),YP(8)
                C     DETERMINE AMBIENT CONDITIONS
0005                  TPK=TP+273.16
0006                  TOK=TO(ITHP)+273.16
0007                  DO 88 I=2,MG
0008                  IF(Y(7) .GT. AZ(I)) GO TO 88
0009                  II=I-1
0010                  DZZ=Y(7)-AZ(II)
0011                  TA=AT(II)+ATG(II)*DZZ
0012                  HA=AH(II)+AHG(II)*DZZ
0013                  UA=AU(ITHP,II)+AUG(ITHP,II)*DZZ
0014                  TG=ATG(II)
0015                  HG=AHG(II)
0016                  GO TO 90
0017               88 CONTINUE
0018                  DZ1=Y(7)-AZ(MG1)
0019                  TA=AT(MG1)+ATG(MG1)*DZ1
0020                  HA=AH(MG1)+AHG(MG1)*DZ1
0021                  UA=AU(ITHP,MG1)+AUG(ITHP,MG1)*DZ1
0022                  HG=AHG(MG1)
0023                  TG=ATG(MG1)
0024               90 TAK=TA+273.16
0025                  UP=UA*TURBF
                C     DETERMINE MOMENTUM,TRAJECTORY AND VELOCITY OF PLUME
0026                  PM=SQRT(Y(2)*Y(2)+Y(3)*Y(3))
0027                  PCOS=Y(2)/PM
0028                  PSIN=Y(3)/PM
0029                  IF(PCOS .NE. 0.) GO TO 86
0030                  ANG=90.
0031                  GO TO 85
0032               86 ANG=ATAN(PSIN/PCOS)*180./PAI
0033               85 SIGN=1.
0034                  IF(PSIN .LT. 0.) SIGN=-1.
0035                  APSIN=ABS(PSIN)
0036                  SY=PSIN*Y(1)
0037                  UC=PM/Y(1)
0038                  U=UC-UA*PCOS
0039                  SPM=SQRT(PAI*PM)
0040                  B=Y(1)/SPM
0041                  USU=UC*PAI*B*B
0042                  PMC=CD*B*UA*UA*PSIN*PSIN
0043                  Y4=Y(4)/USU
0044                  Y5=Y(5)/USU
0045                  C1=ALV/CPA
0046                  C2=Y4+TA+C1*(Y5+HA)
0047                  C3=Y5+HA
                C     TO ASSUME THE PLUME IS SATURATED AND CALCULATE THE SATURATED PLU
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FORTRAN IV G LEVEL 20.7 VS              DERIVR              DATE =     6/07/77      15:27:

                C       HUMIDITY AND TEMPERATURE
0048                    CALL ITER(TPK,HP,EST,C1,C2)
                C       TO DETERMINE THE PLUME LIQUID PHASE MOISTURE
0049                    WP=C3-HP
0050                    IF(WP .GT. 0.) GO TO 79
                C       DRY PLUME
0051                    WP=0.
0052                    HP=C3
0053                    TP=TA+Y4
0054                    TPK=TP+273.16
0055                    GO TO 178
                C       WET PLUME
0056                 79 TP=TPK-273.16
0057                178 ET=TP-TA
0058                    EH=HP-HA
                C       TO DETERMINE ADIABATIC LAPSE RATE
0059                    GAMA=FGAMA(TAK,HA)
                C       DETERMINE PLUME ENTRAINMENT
0060                    RT=TPK/TAK
0061                    PER=2.*PAI*B
0062                    IF(RT .EQ. 1.) GO TO 99
0063                    FRL=UC*UC*TPK/(GRA*TCK*ABS(RT-1.)*B)
0064                    IF(FRL .GT. CFRL) GO TO 9
0065                    A12=0.116
0066                    GO TO 10
0067                  9 A12=A1+A2*APSIN/FRL
0068                    GO TO 10
0069                 99 A12=A1
0070                 10 ENTRAN=PER*(A12*ABS(U)+A3*UA*APSIN*PCOS+A4*UP)
                C       EQUATIONS OF CONSERVATION OF VOLUME,MOM.,ENERGE AND MOIST. FLUXES
0071                    YP(1)=ENTRAN*RT
0072                    YP(2)=(UA*ENTRAN+PMC*APSIN)*RT
0073                    YP(3)=(RT-1.-WP)*GRA*LSL/UC-SIGN*PMC*PCOS*RT
0074                    YP(4)=-(TG+GAMA)*SY
0075                    YP(5)=-HG*SY
0076                    YP(6)=PCOS
0077                    YP(7)=PSIA
0078                    RETURN
0079                    END
```

```
FORTRAN IV G LEVEL 20.7 VS              DERIVS              DATE =     6/07/77      15:27:
0001                  SUBROUTINE DERIVS(S,N,Y,YP)
0002                  DOUBLE PRECISION AQ,BC,CC,DQ
0003                  COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
                     1        /STORE3/AH(30),AT(30),AZ(30),AHG(30),ATG(30),AU(30,30),
                     A                ALG(30,30)
                     3        /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WF,
                     4                MG,MG1,CFRL,ALV,CPA,ANG,IC,ITHP,ENTRAN
                     5        /CONST3/AC,BC,CC,DQ
                     6        /STORE5/DI(30),UC(30),TO(30),HO(30),WO(30)
0004                  DIMENSION Y(8),YP(8)
0005                  TPK=TP+273.16
                C     DETERMINE AMBIENT CONDITIONS
0006                  TOK=TO(ITHP)+273.16
0007                  DO 88 I=2,MG
0008                  IF(Y(7) .GT. AZ(I)) GO TO 88
0009                  II=I-1
0010                  DZZ=Y(7)-AZ(II)
0011                  TA=AT(II)+ATG(II)*DZZ
0012                  HA=AH(II)+AHG(II)*DZZ
0013                  UA=AU(ITHP,II)+AUG(ITHP,II)*DZZ
0014                  TG=ATG(II)
0015                  HG=AHG(II)
0016                  GO TO 90
0017               88 CONTINUE
0018                  DZ1=Y(7)-AZ(MG1)
0019                  TA=AT(MG1)+ATG(MG1)*DZ1
0020                  HA=AH(MG1)+AHG(MG1)*DZ1
0021                  UA=AU(ITHP,MG1)+AUG(ITHP,MG1)*DZ1
0022                  TG=ATG(MG1)
0023                  HG=AHG(MG1)
0024               90 TAK=TA+273.16
0025                  UP=UA*TURBF
                C     DETERMINE MOMENTUM,TRAJECTORY AND VELOCITY OF PLUME
0026                  PM=SQRT(Y(2)*Y(2)+Y(3)*Y(3))
0027                  PCOS=Y(2)/PM
0028                  PSIN=Y(3)/PM
0029               85 SIGN=1.
0030                  IF(PSIN .LT. 0.) SIGN=-1.
0031                  APSIN=ABS(PSIN)
0032                  SY=PSIN*Y(1)
0033                  UC=PM/Y(1)
0034                  U=UC-UA*PCOS
0035                  B=Y(1)*Y(1)/(2.*PM)
0036                  USU=2.*B*UC
0037                  PMC=CD*UA*UA*PSIN*PSIN*0.5
0038                  Y4=Y(4)/USU
0039                  Y5=Y(5)/USU
0040                  C1=ALV/CPA
0041                  C2=Y4+TA+C1*(Y5+HA)
0042                  C3=Y5+HA
                C     TO ASSUME THE PLUME IS SATURATED AND CALCULATE THE SATURATED PLUME
                C     HUMIDITY AND TEMPERATURE
0043                  CALL ITER(TPK,HP,EST,C1,C2)
                C     TO DETERMINE THE PLUME LIQUID PHASE MOISTURE
0044                  WP=C3-HP
0045                  IF(WP .GT. 0.) GO TO 79
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FORTRAN IV G LEVEL 20.7 VS              DERIVS              DATE =     6/07/77      15:27:

                C       DRY PLUME
0046                    WP=0.
0047                    HP=C3
0048                    TP=TA+Y4
0049                    TPK=TP+273.16
0050                    GO TO 178
                C       WET PLUME
0051               79   TP=TPK-273.16
0052              178   ET=TP-TA
0053                    EH=HP-HA
                C       TO DETERMINE ADIABATIC LAPSE RATE
0054                    GAMA=FGAMA(TAK,PA)
                C       DETERMINE PLUME ENTRAINMENT
0055                    TPK=TP+273.16
0056                    RT=TPK/TAK
0057                    ENTRAN=2.*(0.198*ABS(U)+A3*UA*APSIN*PCOS+A4*UP)
                C       EQUATIONS OF CONSERVATION OF VOLUME,MOM.,ENERGE AND MOIS T. FLUXES
0058                    YP(1)=ENTRAN*RT
0059                    YP(2)=(UA*ENTRAN+PMC*APSIN)*RT
0060                    YP(3)=(RT-1.-WP)*GRA*LSL/UC-SIGN*PMC*PCOS*RT
0061                    YP(4)=-(TG+GAMA)*SY
0062                    YP(5)=-HG*SY
0063                    YP(6)=PCOS
0064                    YP(7)=PSIN
0065                    RETURN
0066                    END
```

```
FORTRAN IV G LEVEL 20.7 VS              DERIVE              DATE =     6/07/77      15:27:

0001                  SUBROUTINE DERIVE(S,N,Y,YP)
0002                  DOUBLE PRECISION AQ,BQ,CQ,DQ
0003                  COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
                     1       /STORE3/AH(30),AT(30),AZ(30),AHG(30),ATG(30),AU(30,30),
                     A              AUG(30,30)
                     2       /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
                     3              PMSIN(30),DW(30),NEV(30),NEV(30),NCV(30)
                     4       /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HF,EM,WP,
                     5              MG,MG1,CFRL,ALV,CPA,ANG,IC,ITHP,ENTRAN
                     6       /CONST3/AQ,BQ,CQ,DQ
                     7       /STORE5/DI(30),UC(30),TO(30),HO(30),WO(30)
0004                  DIMENSION Y(8),YP(8)
0005                  TPK=TP+273.16
                C     DETERMINE AMBIENT CONDITIONS
0006                  TOK=TO(ITHP)+273.16
0007                  DO 88 I=2,MG
0008                  IF(Y(7) .GT. AZ(I)) GO TO 88
0009                  II=I-1
0010                  DZZ=Y(7)-AZ(II)
0011                  TA=AT(II)+ATG(II)*DZZ
0012                  HA=AH(II)+AHG(II)*DZZ
0013                  UA=AU(ITHP,II)+AUG(ITHP,II)*DZZ
0014                  TG=ATG(II)
0015                  HG=AHG(II)
0016                  GO TO 90
0017               88 CONTINUE
0018                  DZ1=Y(7)-AZ(MG1)
0019                  TA=AT(MG1)+ATG(MG1)*DZ1
0020                  HA=AH(MG1)+AHG(MG1)*DZ1
0021                  UA=AU(ITHP,MG1)+AUG(ITHP,MG1)*DZ1
0022                  TG=ATG(MG1)
0023                  HG=AHG(MG1)
0024               90 TAK=TA+273.16
0025                  UP=UA*TURBF
                C     DETERMINE MOMENTUM,TRAJECTORY AND VELOCITY OF PLUME
0026                  PM=SQRT(Y(2)*Y(2)+Y(3)*Y(3))
0027                  PCOS=Y(2)/PM
0028                  PSIN=Y(3)/PM
0029                  IF(PCOS .NE. 0.) GO TO 86
0030                  ANG=90.
0031                  GO TO 85
0032               86 ANG=ATAN(PSIN/PCOS)*180./PAI
0033               85 SIGN=1.
0034                  IF(PSIN .LT. 0.) SIGN=-1.
0035                  APSIN=ABS(PSIN)
0036                  SY=PSIN*Y(1)
0037                  UC=PM/Y(1)
0038                  U=UC-UA*PCOS
0039                  USU=UC*(A(ITHP)*(B1(ITHP)+B2(ITHP))+0.5*PAI*(B1(ITHP)*B1(ITHP)+
                     1B2(ITHP)*B2(ITHP)))
0040                  PMC=0.5*CD*UA*UA*PSIN*PSIN*DW(ITHP)
0041                  Y4=Y(4)/USU
0042                  Y5=Y(5)/USU
0043                  C1=ALV/CPA
0044                  C2=Y4+TA+C1*(Y5+HA)
0045                  C3=Y5+HA
```

```
FORTRAN IV G LEVEL 20.7 VS                DERIVE                DATE =     6/07/77      15:27:

                C       TO ASSUME THE PLUME IS SATURATED AND CALCULATE THE SATURATED PLUM
                C       HUMIDITY AND TEMPERATURE
0046                    CALL ITER(TPK,HP,EST,C1,C2)
                C       TO DETERMINE THE PLUME LIQUID PHASE MOISTURE
0047                    WP=C3-HP
0048                    IF(WP .GT. 0.) GO TO 79
                C       DRY PLUME
0049                    WP=0.
0050                    HP=C3
0051                    TP=TA+Y4
0052                    TPK=TP+273.16
0053                    GO TO 178
                C       WET PLUME
0054                 79 TP=TPK-273.16
0055                178 ET=TP-TA
0056                    EH=HP-HA
                C       TO DETERMINE ADIABATIC LAPSE RATE
0057                    GAMA=FGAMA(TAK,HA)
                C       DETERMINE PLUME ENTRAINMENT
0058                    TPK=TP+273.16
0059                    RT=TPK/TAK
0060                    PER=2.*A(ITHP)
0061                    A12=0.198
0062                    IF(RT .EQ. 1.) GO TO 99
0063                    FRC=UC*UC*TPK/(GRA*TCK*ABS(RT-1.))
0064                    FRL=FRC/B1(ITHP)
0065                    IF(FRL .GT. CFRL) GO TO 106
0066                    B12=0.116
0067                    GO TO 108
0068                106 B12=A1+A2*APSIN/FRL
0069                108 FRL=FRC/B2(ITHP)
0070                    IF(FRL .GT. CFRL) GO TO 104
0071                    C12=0.116
0072                    GO TO 107
0073                104 C12=A1+A2*APSIN/FRL
0074                    GO TO 107
0075                 99 B12=A1
0076                    C12=A1
                C       ENTRAINMENT OF TWO HALF ROUND ENDING PLUMES
0077                107 ENTR=PAI*(ABS(U)*(B1(ITHP)*B12+B2(ITHP)*C12)+(B1(ITHP)+B2(ITHP))
                       1*(A3*UA*APSIN*PCOS+A4*UP))
                C       ENTRAINMENT OF THE HALF ROUND PLUMES AND SLOT JET
0078                    ENTRAN=PER*(A12*ABS(U)+A3*UA*APSIN*PCOS+A4*UP)+ENTR
                C       EQUATIONS OF CONSERVATION OF VOLUME,MOM.,ENERGE AND MOIST. FLUXES
0079                    YP(1)=ENTRAN*RT
0080                    YP(2)=(UA*ENTRAN+PMC*APSIN)*RT
0081                    YP(3)=(RT-1.-WP)*GRA*LSU/UC-SIGN*PMC*PCOS*RT
0082                    YP(4)=-(TG+GAMA)*SY
0083                    YP(5)=-HG*SY
0084                    YP(6)=PCOS
0085                    YP(7)=PSIN
0086                    RETURN
0087                    END
```

```
FORTRAN IV G LEVEL 20.7 VS              PHI                    DATE =     6/07/77      14:32

0001                  SUBROUTINE PHI(I,JR,M,CY,PZ,NP,NS,IKQ,IKP)
0002                  COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
                     1       /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
                     2              PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
0003                  DIMENSION PZ(NP,NS),CY(30)
                C     TO CALCULATE THE ANGLE OF THE INCLINATION OF MERGED PLUME (PHI)
0004                  IJR=INDT(JR)
0005                  IM=INDT(M)
0006                  IF(IJR .NE. IM) GO TO 1
0007                  IF(IJR .EQ. 1 .AND. IM .EQ. 1) GO TO 2
0008                  IF(JR .EQ. M) GO TO 6
0009                  IF(IJR .EQ. 2 .AND. IM .EQ. 2) GO TO 4
0010                2 DY=ABS(CY(JR)-CY(M))
0011                  DZ=ABS(PZ(JR,IKP)-PZ(M,IKQ))
0012                  DS=SQRT(DY*DY+DZ*DZ)
0013                  PMCOS(I)=DY/DS
0014                  PMSIN(I)=DZ/DS
0015                  GO TO 5
0016                1 IF(IJR .NE. 1) GO TO 6
0017                7 PMCOS(I)=PMCOS(M)
0018                  PMSIN(I)=PMSIN(M)
0019                  GO TO 5
0020                6 PMCOS(I)=PMCOS(JR)
0021                  PMSIN(I)=PMSIN(JR)
0022                  GO TO 5
0023                4 COSS=PMCOS(JR)*PMCOS(M)-PMSIN(JR)*PMSIN(M)
0024                  PMCOS(I)=SQRT(0.5*(1.+COSS))
0025                  PMSIN(I)=SQRT(0.5*(1.-COSS))
0026                5 RETURN
0027                  END
```

```
FORTRAN IV G LEVEL 20.7 VS              ITER                    DATE =     6/07/77      14:3
0001                  SUBROUTINE ITER(TPK,HP,EST,C1,C2)
0002                1 TS=373.16/TPK
0003                  T=1.-TS
0004                  EST=1013.25*EXP((13.3185-(1.976+(0.6445+0.1299*T)*T)*T)*T)
0005                  ES=0.622*EST
0006                  HP=ES/(1013.25+ES)
0007                  FTPK=C2-C1*HP+273.16-TPK
0008                  IF(ABS(FTPK) .LT. 0.01) RETURN
0009                  DST=(13.3185-(3.952+(1.9335+0.5196*T)*T)*T)*TS/TPK
0010                  FTPKD=-1.+C1*HP*DST*(HP-1.)
0011                  TPK=TPK-FTPK/FTPKD
0012                  GO TO 1
0013                  END
```

```
FORTRAN IV G LEVEL 20.7 VS              FGAMA                DATE =     6/07/77      14:32

0001                  FUNCTION FGAMA(TAK,HA)
                C     TO DETERMINE ADIABATIC LAPSE RATE
0002                  T=1.-373.16/TAK
0003                  EST=EXP((13.3185-(1.976+(0.6445+0.1229*T)*T)*T)*T)
0004                  ES=0.622*1013.25*EST
0005                  HAS=0.99*ES/(1013.25+ES)
0006                  IF(HA .GE. HAS) GO TO 1
                C     DRY ADIABATIC LAPSE RATE
0007                  FGAMA=0.00976
0008                  GO TO 2
0009                1 RESP=EST/TAK
                C     SATURATED ADIABATIC LAPSE RATE
0010                  FGAMA=0.00976*(1.+5420.*RESP)/(1.+839000.*RESP/TAK)
0011                2 RETURN
0012                  END
```

```
FORTRAN IV G LEVEL 20.7 VS              SOLUTN              DATE =     6/07/77      14:32:

0001          SUBROUTINE SOLUTN(PX,PY,PZ,PQ,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PCOS,
             1PSIN,PT,PET,PH,PEH,PW,PAN,PDIL,PC,CY,Y,YP,S,I,J,NP,NS)
0002          COMMON /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
             1                 PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
             2        /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
             3                 MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
             4        /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
0003          DIMENSION PX(NP,NS),PY(NP,NS),PZ(NP,NS),PQ(NP,NS),PMX(NP,NS),
             1PMZ(NP,NS),PG(NP,NS),PF(NP,NS),PU(NP,NS),PENT(NP,NS),PS(NP,NS),
             2PA(NP,NS),PB(NP,NS),PCOS(NP,NS),PSIN(NP,NS),PT(NP,NS),PET(NP,NS),
             3PH(NP,NS),PEH(NP,NS),PW(NP,NS),PAN(NP,NS),PDIL(NP,NS),CY(30),Y(8),
             4YP(8),PC(NP,NS)
0004          PX(I,J)=Y(6)
0005          PZ(I,J)=Y(7)
0006          PY(I,J)=CY(I)
0007          PQ(I,J)=Y(1)
0008          PMX(I,J)=Y(2)
0009          PMZ(I,J)=Y(3)
0010          PG(I,J)=Y(4)
0011          PF(I,J)=Y(5)
0012          PU(I,J)=UC
0013          PENT(I,J)=ENTRAN
0014          PS(I,J)=S
0015          PA(I,J)=A(I)
0016          PC(I,J)=BXZ(I)
0017          PB(I,J)=B
0018          PCOS(I,J)=YP(6)
0019          PSIN(I,J)=YP(7)
0020          PT(I,J)=TP
0021          PET(I,J)=ET
0022          PH(I,J)=HP
0023          PEH(I,J)=EH
0024          PW(I,J)=WP
0025          PAN(I,J)=ANG
0026          PDIL(I,J)=Y(1)/PQ(I,1)
0027          RETURN
0028          END
```

```
FORTRAN IV G LEVEL 20.7 VS              CHKNWP              DATE =     6/07/77      14:32:

0001                  SUBROUTINE CHKNWP(PX,PZ,PQ,PMX,PMZ,PG,PF,PCOS,PSIN,PENT,PU,PS,PB,
                     1PA,PT,PET,PH,PEH,PW,PAN,PY,PDIL,PC,CX,NP,NS,DERIVR,CY,KE)
0002                  EXTERNAL DERIVR
0003                  COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
                     1        /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
                     2                PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
                     3        /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
                     4                MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
                     5        /CONST2/IL,NII,IK,NI,NIP1
                     6        /STORE5/DI(30),UO(30),TO(30),HC(30),WO(30)
0004                  DIMENSION PX(NP,NS),PZ(NP,NS),PQ(NP,NS),PMX(NP,NS),PMZ(NP,NS),
                     1PB(NP,NS),PU(NP,NS),PF(NP,NS),PG(NP,NS),PCOS(NP,NS),PSIN(NP,NS),
                     2PENT(NP,NS),PA(NP,NS),PT(NP,NS),CX(30),Y(8),YP(8),PS(NP,NS),
                     3PH(NP,NS),PW(NP,NS),PET(NP,NS),PEH(NP,NS),PAN(NP,NS),PY(NP,NS),
                     4PDIL(NP,NS),CY(30),KE(30),PC(NP,NS)
                C     CHECK IF ANY NEW PLUME APPEARS
0005                  IKK=IK+NOVIK(1)-IS(1)
0006                  IF(PX(1,IKK) .LT. CX(NIP1)) GO TO 19
0007                  NIPP=NIP1
0008                  DO 22 J=NIPP,NP
0009                  DS=DI(J)/20.
0010                  IF(ABS(CX(NIPP)-CX(J)) .GE. DS) GO TO 22
0011                  NI=NI+1
0012                  WRITE(6,40)J,IKK
0013             40 FORMAT(1X,'PLUME',2X,I3,'  APPEARS AT NSTEP=',I5//)
0014                  NII=1
0015                  IS(J)=IKK
0016                  NOVIK(J)=NOVIK(1)
0017                  NIP1=J+1
0018                  IND(J)=1
0019                  IKS=1
                C     SET INITIAL CONDITIONS
0020                  TP=TO(J)
0021                  ALV=FALV(TP)
0022                  CALL SETIC(Y,J,CX)
0023                  L=0
0024                  S=0.
0025                  ITHP=J
0026             30 CALL RUNGS(S,DS,7,Y,YP,L,DERIVR)
0027                  BXZ(J)=B
                C     SOLUTIONS FOR UNMERGED SINGLE ROUND PLUME
0028                  CALL SOLUTN(PX,PY,PZ,PQ,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PCOS,PSIN,
                     1PT,PET,PH,PEH,PW,PAN,PDIL,PC,CY,Y,YP,S,J,IKS,NP,NS)
                C     CHECKING THE CRITERION FOR STOPPING THE CALCULATION OF THE NEW
                C     ISSUED SINGLE PLUME
0029                  IF(PZ(J,IKS) .GE. PZ(1,IKK)) GO TO 23
0030                  IF(IKS .GE. NS) GO TO 22
0031                  IKS=IKS+1
0032                  DS=B*0.1
0033                  ALV=FALV(TP)
0034                  GO TO 30
0035             23 KE(J)=IKS
0036             22 CONTINUE
0037             19 RETURN
0038                  END
```

```
FORTRAN IV G LEVEL 20.7 VS              ALIGN                   DATE =     6/07/77      14:32:

0001          SUBROUTINE ALIGN(PX,PY,PZ,PQ,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PC,
             1PCOS,PSIN,PI,PET,PH,PEH,PW,PAN,PDIL,CY,Y,YP,YS,YSP,YR1,YR1P,YR2,
             2YR2P,DERIVE,DERIVS,DERIVR,S,LC,NP,NS,KE)
0002          EXTERNAL DERIVE,DERIVS,DERIVR
0003          COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
             1       /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
             2              MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
             3       /CONST2/IL,NII,IK,NI,NIP1
             4       /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
             5              PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
0004          DIMENSION PX(NP,NS),PY(NP,NS),PZ(NP,NS),PQ(NP,NS),PMX(NP,NS),
             1PMZ(NP,NS),PG(NP,NS),PF(NP,NS),PU(NP,NS),PENT(NP,NS),PS(NP,NS),
             2PA(NP,NS),PB(NP,NS),PC(NP,NS),PCOS(NP,NS),PSIN(NP,NS),PT(NP,NS),
             3PET(NP,NS),PH(NP,NS),PEH(NP,NS),PW(NP,NS),PAN(NP,NS),PDIL(NP,NS),
             4CY(30),Y(8),YP(8),YS(8),YSP(8),YR1(8),YR1P(8),YR2(8),YR2P(8),
             5KE(30)
0005          I1=IK+NOVIK(1)-1
0006          PXMAX=PX(1,I1)
0007          DO 1 I=1,NI
0008          IM=IK+NOVIK(I)-IS(I)
0009          IF(PXMAX .LT. PX(I,IM)) PXMAX=PX(I,IM)
0010        1 CONTINUE
0011          DO 2 I=1,NI
0012          IF(IND(I) .LT. 1) GO TO 2
0013          IM=IK+NOVIK(I)-IS(I)
0014       11 IF(IM .GE. NS) GO TO 2
0015          DS=PB(I,IM)*0.1
0016          IF((PXMAX-PX(I,IM)-DS) .LT. 0.) GO TO 2
0017          IM=IM+1
0018          IF(IND(I) .GT. 1) GO TO 8
0019          IF(IM .GT. KE(I)) GO TO 8
0020          B1(I)=PB(I,IM)
0021          B2(I)=PB(I,IM)
0022          BXZ(I)=PB(I,IM)
0023          BY(I)=PB(I,IM)
0024          PC(I,IM)=PB(I,IM)
0025          GO TO 9
0026        8 ITHP=I
0027          IKT=IM
0028          CALL RESETI(I,IKT,DS,S,NP,NS,CY,Y,YP,YS,YSP,YR1,YR1P,YR2,YR2P,
             1DERIVE,DERIVS,DERIVR,PX,PZ,PC,PMX,PMZ,PG,PF,PCOS,PSIN,PENT,PU,PB,
             2PA,PI,PET,PEH,PW,LC)
0029          CALL SOLUTN(PX,PY,PZ,PQ,PMX,PMZ,PG,PF,PU,PENT,PS,PA,PB,PCOS,PSIN,
             1PT,PET,PH,PEH,PW,PAN,PDIL,PC,CY,Y,YP,S,I,IKT,NP,NS)
0030        9 NOVIK(I)=NOVIK(I)+1
0031          GO TO 11
0032        2 CONTINUE
0033          RETURN
0034          END
```

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FORTRAN IV G LEVEL 20.7 VS              PLMERG              DATE =     6/07/77      14:32:

0001          SUBROUTINE PLMERG(PX,PY,PZ,PT,PET,PH,PEH,PW,PA,PB,PAN,PDIL,PCOS,
             1PSIN,CY,NP,NS,KE,MGPA2,MGST1,PC,LCHK,PU)
0002          COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
             1       /STORE2/MP(30),MS(30),IIP(30)
             2       /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
             3              PMSIN(30),DW(30),NBV(30),NEV(30),NCV(30)
             4       /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HP,EH,WP,
             5              MG,MG1,CFRL,ALV,CPA,ANG,IQ,ITHP,ENTRAN
             6       /CONST2/IL,NII,IK,NI,NIP1
0003          DIMENSION PX(NP,NS),PZ(NP,NS),PB(NP,NS),PCOS(NP,NS),PXI(30),
             1PYI(30),PZI(30),PBI(30),PCOSI(30),CY(30),IRE(30),PSIN(NP,NS),
             2PSINI(30),KE(30),PY(NP,NS),PT(NP,NS),PET(NP,NS),PH(NP,NS),
             3PEH(NP,NS),PW(NP,NS),PA(NP,NS),PAN(NP,NS),PDIL(NP,NS),MGPA2(30),
             4MGST1(30),PC(NP,NS),B1I(30),B2I(30),BXZI(30),BYI(30),AI(30),
             5LCHK(30),PU(NP,NS)
C             REARRANGE THE TRAJECTORIES OF THE EXISTING PLUMES
0004          NJ=0
0005          DO 101 I=1,NI
0006          IF(IND(I)-1)101,102,102
0007        102 ISC=IK*NOVIK(I)-IS(I)
0008          NJ=NJ+1
0009          PXI(NJ)=PX(I,ISC)
0010          PYI(NJ)=CY(I)
0011          PZI(NJ)=PZ(I,ISC)
0012          PBI(NJ)=PB(I,ISC)
0013          PCOSI(NJ)=PCOS(I,ISC)
0014          PSINI(NJ)=PSIN(I,ISC)
0015          AI(NJ)=A(I)
0016          B1I(NJ)=B1(I)
0017          B2I(NJ)=B2(I)
0018          BXZI(NJ)=BXZ(I)
0019          BYI(NJ)=BY(I)
0020          IRE(NJ)=I
0021        101 CONTINUE
C             CHECK PLUME MERGING
0022          IL=0
0023          NI1=NJ-1
0024          DO 103 I=1,NI1
0025          J1=I+1
0026          DO 103 J=J1,NJ
0027          PYD=ABS(PYI(I)-PYI(J))
0028          PZD=ABS(PZI(I)-PZI(J))
0029          PYZ=SQRT(PZD*PZD+PYD*PYD)
0030          SR=BXZI(I)*PCOSI(I)+BXZI(J)*PCOSI(J)
0031          SR2=BYI(I)+BYI(J)
0032          IF(SR-PZD)103,10,10
0033         10 IF(SR2-PYD)103,104,104
0034        104 IF(AI(I) .EQ. 0. .AND. AI(J) .EQ. 0.) GO TO 1
0035          GO TO 106
0036          1 AREA1=0.5*PAI*(B1I(I)*B1I(I)+B1I(J)*B1I(J))
0037          AREA2=PYZ*(B1I(I)+B1I(J))
0038          IF(AREA1-AREA2) 103,106,106
0039        106 IL=IL+1
C             RECORD THE PAIRS OF THE MERGED PLUMES
0040          MP(IL)=IRE(I)
0041          MS(IL)=IRE(J)
```

```
0042                  II=IRE(I)
0043                  JJ=IRE(J)
0044                  INDT(JJ)=IND(JJ)
0045                  INDT(II)=IND(II)
                C     RESET IND(II)=2,IND(JJ)=0 FOR JJ>II WHEN PLUMES II AND JJ MERGED
0046                  IND(JJ)=0
0047                  IIP(JJ)=IK+NOVIK(JJ)-IS(JJ)
0048                  IF(IND(II)-1) 103,111,113
0049              111 IND(II)=2
0050              113 IIP(II)=IK+NOVIK(II)-IS(II)
0051              103 CONTINUE
0052                  IF(IL-1)16,107,205
0053              205 K=1
0054              206 II=K+1
0055                  DO 200 I=II,IL
0056                  IF(MS(K).NE.MS(I))GO TO 200
0057                  IF(MP(I)-MP(K))204,200,203
0058              203 IF(IND(I).EQ.0)GO TO 200
0059                  IND(I)=0
0060                  IIP(I)=IK+NOVIK(I)-IS(I)
0061                  GO TO 200
0062              204 IF(IND(K).EQ.0)GO TO 200
0063                  IND(K)=0
0064                  IIP(K)=IK+NOVIK(K)-IS(K)
0065              200 CONTINUE
0066                  K=K+1
0067                  IF(K.LT.IL)GO TO 206
                C     PLUME MERGING OCCURS
0068              107 WRITE(6,108)
0069              108 FORMAT(1X,'RESULTS OF THE PAIRS OF MERGED PLUMES AT MERGING PLACE'
                     1)
0070                  WRITE(6,112)
0071              112 FORMAT(1X,'NSTEP   NTHP     X         Z         Y      PTEMP  EXCEST'
                     1,'  PHUMI   EXCESH PLODMOIST PAVHFWD PCROSEC SLOTLEN  PANGLE  ',
                     2'DILUTN  PVELO')
0072                  DO 109 I=1,IL
0073                  INDX=1
0074                  LP=MP(I)
0075                  LS=MS(I)
0076                  MT=IIP(LP)
0077                  NT=IIP(LS)
0078                  MGPA2(LS)=LP
0079                  MGST1(LS)=MT
0080                  IF(KE(LS) .GT. NT) GO TO 116
0081                  LCHK(LS)=1
0082                  KE(LS)=NT
0083              116 WRITE(6,110)MT,LP,PX(LP,MT),PZ(LP,MT),PY(LP,MT),PT(LP,MT),
                     1PET(LP,MT),PH(LP,MT),PEH(LP,MT),PW(LP,MT),PB(LP,MT),PC(LP,MT),
                     2PA(LP,MT),PAN(LP,MT),PDIL(LP,MT),PU(LP,MT)
0084              110 FORMAT(1X,2(I5,1X),3(F8.2,1X),2(F7.2,1X),3(F8.5,1X),6(F7.2,1X))
0085                  IF(INDX-1)117,117,118
0086              117 INDX=2
0087                  LP=LS
0088                  MT=NT
0089                  GO TO 116
0090              118 WRITE(6,119)
```

```
0091          119 FORMAT(/)
0092          105 CONTINUE
0093              DO 777 I=2,NI
0094              IF(IND(I)-1) 777,779,779
0095          777 CONTINUE
0096              NII=0
0097              ITHP=1
0098          779 DO 400 I=2,NP
0099              IF(IND(I))16,400,16
0100          400 CONTINUE
                C     ALL THE PLUMES ARE MERGED WHEN IND(I)=0 FOR 1<I<NP+1
0101              IND(1)=3
0102              IQ=3
0103              NI=1
0104              ITHP=1
0105           16 RETURN
0106              END
```

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FORTRAN IV G LEVEL 20.7 VS              RESETI              DATE =     6/07/77      19:42:
0001          SUBROUTINE RESETI(I,IKT,DS,S,NP,NS,CY,Y,YP,YS,YSP,YR1,YR1P,YR2,
             1YR2P,DERIVE,DERIVS,DERIVR,PX,PZ,PQ,PMX,PMZ,PG,PF,PCOS,PSIN,PENT,
             2PU,PB,PA,PT,PET,PEH,PW,LC)
0002          EXTERNAL DERIVE,DERIVS,DERIVR
0003          COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
             1       /STORE2/MP(30),MS(30),IIP(30)
             2       /STORE4/A(30),B1(30),B2(30),BXZ(30),BY(30),PMCOS(30),
             3               PMSIN(30),CW(30),NBV(30),NEV(30),NCV(30)
             4       /CONST1/PAI,GRA,A1,A2,A3,A4,CD,TURBF,UC,B,TP,ET,HF,EH,WP,
             5               MG,MG1,CFRL,ALV,CPA,ANG,IC,ITHP,ENTRAN
             6       /CONST2/IL,NII,IK,NI,NIP1
0004          DIMENSION PX(NP,NS),PZ(NP,NS),PQ(NP,NS),PMX(NP,NS),PMZ(NP,NS),
             1PB(NP,NS),PF(NP,NS),PG(NP,NS),PENT(NP,NS),IRP(30),COS(30),Y(8),
             2YP(8),CY(30),PT(NP,NS),PET(NP,NS),PU(NP,NS),YS(8),YSP(8),
             3PA(NP,NS),PCOS(NP,NS),PSIN(NP,NS),YR1(8),YR1P(8),YR2(8),YR2P(8),
             4PEH(NP,NS),PW(NP,NS),IH(30)
0005          IK1=IKT-1
0006          Y(1)=PQ(I,IK1)
0007          Y(2)=PMX(I,IK1)
0008          Y(3)=PMZ(I,IK1)
0009          Y(4)=PG(I,IK1)
0010          Y(5)=PF(I,IK1)
0011          Y(6)=PX(I,IK1)
0012          Y(7)=PZ(I,IK1)
0013          APT=PT(I,IK1)
0014          IF(IND(I)-2)29,30,30
0015       30 IF(IL)32,32,33
           C     RESET INITIAL CONDITIONS WHEN ANY NEW PLUME MERGING OCCURS
0016       33 IRP(1)=I
0017          IJK=1
0018          MM=1
0019          JR=1
0020          M=I
0021          JRZ=1
0022          MZ=I
0023          CYMANI=CY(I)+BY(I)
0024          CYMINI=CY(I)-BY(I)
0025          PZMANI=PZ(I,IK1)+BXZ(I)
0026          PZMINI=PZ(I,IK1)-BXZ(I)
0027          CYMAN=CYMANI
0028          CYMIN=CYMINI
0029          PZMAN=PZMANI
0030          PZMIN=PZMINI
0031       60 DO 34 J=1,IL
0032          IF(IRP(MM)-MP(J))34,35,34
0033       35 JJ=PS(J)
0034          DO 86 NR=1,IJK
0035          IF(JJ-IRP(NR))86,34,86
0036       86 CONTINUE
           C     SUMMING UP VOLUME,MOMENTUM,ENERGY AND MOISTURE FLUXES OF THE
           C     MERGED PLUMES
0037          IKP=IK+NOVIK(JJ)-IS(JJ)
0038          Y(1)=Y(1)+PQ(JJ,IKP)
0039          Y(2)=Y(2)+PMX(JJ,IKP)
0040          Y(3)=Y(3)+PMZ(JJ,IKP)
0041          Y(4)=Y(4)+PG(JJ,IKP)
```

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0042                Y(5)=Y(5)+PF(JJ,IKP)
0043                PQ(I,1)=PQ(I,1)+PQ(JJ,1)
0044                APT=APT+PT(JJ,IKP)
0045                IJK=IJK+1
0046                IRP(IJK)=JJ
0047                CYMANC=CY(JJ)+BY(JJ)
0048                CYMINC=CY(JJ)-BY(JJ)
0049                PZMANC=PZ(JJ,IKP)+BXZ(JJ)
0050                PZMINC=PZ(JJ,IKP)-BXZ(JJ)
0051                IF(INDT(JJ) .GT. 1) GO TO 401
0052                IF(INDT(I)-2) 401,400,401
0053            400 IF(IH(I) .GT. 2) GO TO 404
0054                IF(CYMANI .GE. CYMANC .AND. CYMINI .LE. CYMINC) GO TO 3+
0055                GO TO 401
0056            404 IF(PZMANI .GE. PZMANC .AND. PZMINI .LE. PZMINC) GO TO 3+
0057            401 IF(CYMAN .GE. CYMANC) GO TO 244
0058                CYMAN=CYMANC
0059                JR=JJ
0060            244 IF(CYMIN .LE. CYMINC) GO TO 28
0061                CYMIN=CYMINC
0062                M=JJ
0063             28 IF(PZMAN .GE. PZMANC) GO TO 26
0064                PZMAN=PZMANC
0065                JRZ=JJ
0066             26 IF(PZMIN .LE. PZMINC) GO TO 34
0067                PZMIN=PZMINC
0068                MZ=JJ
0069             34 CONTINUE
0070                IF(MM-IJK) 58,59,59
0071             58 MM=MM+1
0072                GO TO 60
0073             59 IF(MM-1) 32,32,859
0074            859 APT=APT/FLOAT(IJK)
0075                Y(7)=0.5*(PZMAN+PZMIN)
                C   LC=0 MEANS CLUSTER OF TOWERS; LC=1 MEANS LINE TOWER ARRAY
0076                IF(LC-1)575,572,575
0077            575 CY(I)=0.5*(CYMAN+CYMIN)
0078                GO TO 571
0079            572 IKQ=IK+NCVIK(M)-IS(M)
0080                IKP=IK+NCVIK(JR)-IS(JR)
0081                DCYAI=CYMAN-CYMIN
0082                DPZAI=PZMAN-PZMIN
0083                IF(DCYAI .LT. DPZAI) GO TO 402
0084                IF((CYMAN-CYMIN) .LT. (PZMAN-PZMIN)) GO TO 402
0085                IF(CY(M) .EQ. CY(JR)) GO TO 407
0086                CYDZ=ABS(PZ(M,IKQ)-PZ(JR,IKP))
                C   TO CALCULATE THE ANGLE OF THE INCLINATION OF MERGED PLUME (PHI)
0087                CALL PHI(I,JR,M,CY,PZ,NF,NS,IKQ,IKP)
0088                IF(CYDZ.NE.0.)GO TO 408
0089                IH(I)=2
0090                GO TO 409
0091            408 IH(I)=1
0092            409 B1(I)=PB(M,IKQ)
0093                B2(I)=PB(JR,IKP)
0094                IF(PMCOS(I) .EQ. 0.) GO TO 988
0095                A(I)=(DCYAI-B1(I)-B2(I))/PMCOS(I)
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FORTRAN IV G LEVEL 20.7 VS              RESETI              DATE =     6/07/77      19:42

0096                    GO TO 573
0097               988  A(I)=DPZAI-B1(I)-B2(I)
0098                    GO TO 573
0099               402  JR=JRZ
0100                    M=MZ
0101                    IKQ=IK+NOVIK(M)-IS(M)
0102                    IKP=IK+NCVIK(JR)-IS(JR)
0103                    IF(PZ(JR,IKP) .EQ. PZ(M,IKQ)) GO TO 407
0104                    PZY=ABS(CY(JR)-CY(M))
                  C     TO CALCULATE THE ANGLE OF THE INCLINATION OF MERGED PLUME (PHI)
0105                    CALL PHI(I,JR,M,CY,PZ,NF,NS,IKQ,IKP)
0106                    IF(PZY.NE.0.)GO TO 431
0107                    IH(I)=3
0108                    GO TO 432
0109               431  IH(I)=1
0110               432  B1(I)=PB(M,IKQ)
0111                    B2(I)=PB(JR,IKP)
0112                    IF(PMSIN(I) .EQ. 0.) GO TO 989
0113                    A(I)=(DPZAI-B1(I)-B2(I))/PMSIN(I)
0114                    GO TO 573
0115               989  A(I)=DCYAI-B1(I)-B2(I)
0116                    GO TO 573
0117               407  A(I)=A(JR)
0118                    B1(I)=B1(JR)
0119                    B2(I)=B2(JR)
0120                    PMCOS(I)=PMCOS(JR)
0121                    PMSIN(I)=PMSIN(JR)
0122                    IH(I)=IH(JR)
0123               573  CY(I)=0.5*(CYMAX+CYMIN)
0124                    IF(A(I) .EQ. 0.)GO TO 38
0125                    GO TO 574
0126                32  IF(LC-1)571,570,571
0127               571  IF(IND(I)-3)29,41,29
0128               570  IF(A(I))38,38,39
0129                38  A(I)=0.
0130                    IF(IND(I)-3)40,41,40
0131                41  IQ=4
0132                    IND(I)=4
0133                    GO TO 29
0134                40  IND(I)=1
0135                    GO TO 29
0136                39  JR=I
0137                    IKP=IK1
0138                    M=I
0139                    IKQ=IK1
                  C     RESET I.C. FOR THE HALF ROUND PLUME
0140               574  BBB=PAI*B1(I)*B1(I)*ABS(PU(M,IKQ))
0141                    ALV1=FALV(PT(M,IKQ))
0142                    ALV2=FALV(PT(JR,IKP))
0143                    YR1(1)=BBB
0144                    YR1(2)=BBB*PU(M,IKQ)*PCOS(M,IKQ)
0145                    YR1(3)=BBB*PU(M,IKQ)*PSIN(M,IKQ)
0146                    YR1(4)=BBB*(PET(M,IKQ)-ALV1*PW(M,IKQ))
0147                    YR1(5)=BBB*(PEH(M,IKQ)+PW(M,IKQ))
0148                    YR1(6)=PX(M,IKQ)
0149                    YR1(7)=PZ(M,IKQ)
```

```
                C       RESET I.C. FOR THE HALF ROUND PLUME
0150                    BBB=PAI*B2(I)*B2(I)*ABS(PU(JR,IKP))
0151                    YR2(1)=BBB
0152                    YR2(2)=BBB*PU(JR,IKP)*PCOS(JR,IKP)
0153                    YR2(3)=BBB*PU(JR,IKP)*PSIN(JR,IKP)
0154                    YR2(4)=BBB*(PET(JR,IKP)-ALV2*PW(JR,IKP))
0155                    YR2(5)=BBB*(PEH(JR,IKP)+PW(JR,IKP))
0156                    YR2(6)=PX(JR,IKP)
0157                    YR2(7)=PZ(JR,IKP)
                C       RESET I.C. FOR THE CENTRAL SLOT JET
0158                    YS(1)=(Y(1)-0.5*(YR1(1)+YR2(1)))/A(I)
0159                    YS(2)=(Y(2)-0.5*(YR1(2)+YR2(2)))/A(I)
0160                    YS(3)=(Y(3)-0.5*(YR1(3)+YR2(3)))/A(I)
0161                    YS(4)=(Y(4)-0.5*(YR1(4)+YR2(4)))/A(I)
0162                    YS(5)=(Y(5)-0.5*(YR1(5)+YR2(5)))/A(I)
0163                    YS(6)=Y(6)
0164                    YS(7)=Y(7)
                C       CALCULATE NEW HALF WIDTH AND VELO. OF THE HALF ROUND PLUME
0165                    L=0
0166                    ALV=ALV1
0167                    CALL RUNGS(S,DS,5,YR1,YR1P,L,DERIVR)
0168                    CALL RUNGS(S,DS,5,YR1,YR1P,L,DERIVR)
0169                    BR1=B
0170                    UR1=UC
0171                    S=S-DS
                C       CALCULATE NEW HALF WIDTH AND VELO. OF THE HALF ROUND PLUME
0172                    L=0
0173                    ALV=ALV2
0174                    CALL RUNGS(S,DS,5,YR2,YR2P,L,DERIVR)
0175                    CALL RUNGS(S,DS,5,YR2,YR2P,L,DERIVR)
0176                    BR2=B
0177                    UR2=UC
0178                    S=S-DS
                C       CALCULATE NEW HALF WIDTH AND VELO. OF THE SLOT JET
0179                    L=0
0180                    ALV=FALV(APT)
0181                    CALL RUNGS(S,DS,5,YS,YSP,L,DERIVS)
0182                    CALL RUNGS(S,DS,5,YS,YSP,L,DERIVS)
0183                    BS=B
0184                    US=UC
0185                    S=S-DS
                C       CALCULATE MERGED PLUME WITH THE MODIFIED PLUME SHAPE DETERMINED C
                C       THE PREVIOUS STEP
0186                    L=0
0187                    CALL RUNGS(S,DS,7,Y,YP,L,DERIVE)
0188                    CALL RUNGS(S,DS,7,Y,YP,L,DERIVE)
                C       DETERMINE B1,B2 AND A OF THE MODIFIED PLUME SHAPE FOR CALCULATING
                C       ENTRAINMENT AND DRAG FOR NEXT STEP
0189                    UU=UC
0190                    W=A(I)
0191                    CB1=BR2/BR1
0192                    CB2=W*BR1*BR2
0193                    CB3=(1.5707963*(BR1*BR1*UR1+BR2*BR2*UR2)+2.*BS*W*US)/UU
0194                    CB4=1.+CB1
0195                    AP1=1.5707963*(1.+CB1*CB1)-CB4*CB4
0196                    BP1=CB2*CB4
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0197                CP1=-CB3
0198                B1P=B1(I)
0199                B2P=B2(I)
0200                AP=A(I)
                C   THE DETERMINED B1,B2 AND A
0201                B1(I)=(-BP1+SQRT(BP1*BP1-4.*AP1*CP1))/(2.*AP1)
0202                B2(I)=CB1*B1(I)
0203                A(I)=CB2-CB4*B1(I)
0204                B=(B1(I)+B2(I))*0.5
0205                IF(A(I))418,418,419
0206           418  A(I)=0.
0207                IF(IND(I)-3) 420,421,420
0208           421  IQ=4
0209                IND(I)=4
0210                GO TO 31
0211           420  IND(I)=1
0212                GO TO 31
0213           419  DY=0.5*(B2(I)-B1(I)+(B1P-B2P)*A(I)/AP)*ABS(PMCOS(I))
0214                CY(I)=CY(I)+DY
                C   DETERMINE SOME LENGTH SCALES FOR THE USE OF MERGING CRITERION
0215                AL=0.5*(B1(I)+B2(I))
0216                ALC=AL+0.5*PMCOS(I)*A(I)
0217                ALS=AL+0.5*PMSIN(I)*A(I)
0218                LQ=IH(I)
0219                GO TO (411,412,413),LC
0220           411  BY(I)=ALC
0221                BXZ(I)=ALS
0222                GO TO 416
0223           412  BY(I)=ALC
0224                BXZ(I)=AMAX1(B1(I),B2(I))
0225                GO TO 416
0226           413  BXZ(I)=ALS
0227                BY(I)=AMAX1(B1(I),B2(I))
0228           416  DW(I)=2.*BY(I)
0229                GO TO 31
                C   CALCULATE SINGLE ROUND PLUME
0230            29  L=0
0231                ALV=FALV(PT(I,IK1))
0232                CALL RUNGS(S,DS,7,Y,YF,L,DERIVR)
0233                CALL RUNGS(S,DS,7,Y,YF,L,DERIVR)
0234                B1(I)=B
0235                B2(I)=B
0236                BXZ(I)=B
0237                BY(I)=B
0238            31  RETURN
0239                END
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FORTRAN IV G LEVEL 20.7 VS              OUTPUT              DATE =     6/07/77      19:42:

0001          SUBROUTINE OUTPUT(PX,PY,PZ,PT,PET,PH,PEH,PW,PA,PC,PAN,PDIL,PSIN,
             1PCOS,CONTA,CONTB,CONTC,KE,INTPR,IFNT,NX,NY,NCONT,N4,NP,NS,IX,DX,
             2DZ,XO,ZO,PB,PS,PU)
0002          COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
             1       /CONTUU/WIDTH,HITE,MORE,NOMAP,ICENT,NOTICK,HEDN(10),
             2            LABY(5),LABX(5)
             3       /STORE5/DI(30),UO(30),TO(30),HO(30),WO(30)
0003          DIMENSION PX(NP,NS),PY(NP,NS),PZ(NP,NS),PT(NP,NS),PET(NP,NS),
             1PH(NP,NS),PEH(NP,NS),PW(NP,NS),PA(NP,NS),PC(NP,NS),PAN(NP,NS),
             2PDIL(NP,NS),PSIN(NP,NS),PCOS(NP,NS),CONTA(NX,NY),CONTB(NCONT),
             3CONTC(N4),KE(30),IX(12),PB(NP,NS),PS(NP,NS),PU(NP,NS)
0004          IF(INTPR .LE. 0) GO TO 10
0005          WRITE(6,1)
0006        1 FORMAT(1X,'DETAILED RESULTS OF PLUME 1')
0007          WRITE(6,2)
0008        2 FORMAT(1X,'NSTEP   NTPP      X         Z         Y      PTEMP  EXCEST
             1,'  PHUMI    EXCESH PLODMOIST PAVHFWD PCROSEC SLOTLEN  PANGLE  ',
             2'DILUTN  PVELO')
0009          I=1
0010          DO 3 J=1,NS,INTPR
0011        3 WRITE(6,241)J,I,PX(I,J),PZ(I,J),PY(I,J),PT(I,J),PET(I,J),PH(I,J),
             1PEH(I,J),PW(I,J),PB(I,J),PC(I,J),PA(I,J),PAN(I,J),PDIL(I,J),
             2PU(I,J)
0012      241 FORMAT(1X,2(I5,1X),3(F8.2,1X),2(F7.2,1X),3(F8.5,1X),6(F7.2,1X))
0013       10 IF(IX(3))15,21,20
0014       20 READ(5,22)DX,DZ,XO,ZO
0015       22 FORMAT(4F10.5)
0016       21 IF(IX(11) .LE. 0) GO TO 26
0017          READ(5,28)WIDTH,HITE,MORE,NOMAP,ICENT,NOTICK
0018       28 FORMAT(2F10.5,4I4)
0019          NCONB=-NCONT
0020       26 PETO=PMAX(PET,NP,NS,KE)
0021          PEHC=PMAX(PEH,NP,NS,KE)
0022          PEWC=PMAX(PW,NP,NS,KE)
0023          IF(PETO .GT. 0.) GO TO 14
0024          IX(8)=0
0025          PETO=1.
0026          WRITE(6,40)
0027       40 FORMAT(1X,'NO EXCESS TEMP PLOT DUE TO ZERO OR NEGATIVE EXCESS',
             1' TEMPERATURE')
0028       14 IF(PEHC .GT. 0.) GO TO 42
0029          IX(9)=0
0030          PEHC=1.
0031          WRITE(6,43)
0032       43 FORMAT(1X,'NO EXCESS HUMI PLOT DUE TO ZERO OR NEGATIVE EXCESS',
             1' HUMIDITY')
0033       42 IF(PEWC .GT. 0.) GO TO 47
0034          IX(10)=0
0035          PEWC=1.
0036          WRITE(6,46)
0037       46 FORMAT(1X,'NO EXCESS LIQUID PHASE MOISTURE PLOT DUE TO ZERO OR',
             1' NEGATIVE EXCESS LIQUID PHASE MOISTURE')
           C     DETERMINE GRID DISTRIBUTION
0038       47 DO 11 I=1,NP
0039          DO 11 J=1,NS
0040          PX(I,J)=PX(I,J)/CI(1)
```

```
FORTRAN IV G LEVEL 20.7 VS                OUTPUT                DATE =     6/07/77      19:42:

0041                PZ(I,J)=PZ(I,J)/DI(1)
0042                PB(I,J)=PB(I,J)/DI(1)
0043                PC(I,J)=PC(I,J)/DI(1)
0044                PS(I,J)=PS(I,J)/DI(1)
0045                PW(I,J)=PW(I,J)/PEWO
0046                PEH(I,J)=PEH(I,J)/PEHC
0047             11 PET(I,J)=PET(I,J)/PETC
0048                I=8
0049                IF(IX(I) .LE. 0) GO TO 5
0050                CALL GRD2(CONTA,DX,DZ,PX,PZ,PC,PET,PCOS,PSIA,NP,NS,KE,XO,ZO,NX,NY)
0051                WRITE(6,31)
0052             31 FORMAT(1X,'EXCESS TEMPERATURE PLOT',///)
0053                GO TO 37
0054              8 CALL GRD2(CONTA,DX,DZ,PX,PZ,PC,PEH,PCOS,PSIA,NP,NS,KE,XO,ZO,NX,NY)
0055                WRITE(6,32)
0056             32 FORMAT(1X,'EXCESS SPECIFIC HUMIDITY PLOT',///)
0057                GO TO 37
0058              9 CALL GRD2(CONTA,DX,DZ,PX,PZ,PC,PW,PCOS,PSIA,NP,NS,KE,XO,ZO,NX,NY)
0059                WRITE(6,33)
0060             33 FORMAT(1X,'EXCESS LIQUID PHASE MOISTURE PLOT',///)
0061             37 READ(5,30) (HEDN(K),K=1,10),(LABY(L),L=1,5),(LABX(M),M=1,5)
0062             30 FORMAT(20A4)
0063              7 CALL CONTU(CONTA,CONTE,CONTC,NX,NY,NCONB,IFAT)
0064              5 I=I+1
0065                IF(I-10)16,17,15
0066             16 IF(IX(I))5,5,8
0067             17 IF(IX(I))5,5,9
0068             15 RETURN
0069                END
```

```
FORTRAN IV G LEVEL 20.7 VS              PMAX                    DATE =     6/07/77      14:32

0001                  FUNCTION PMAX(PT,NP,NS,KE)
0002                  DIMENSION PT(NP,NS),KE(30)
0003                  PMAX=PT(1,1)
0004                  DO 1 I=1,NP
0005                  K=KE(I)
0006                  DO 1 J=1,K
0007                  IF(PT(I,J) .GT. PMAX) PMAX=PT(I,J)
0008                1 CONTINUE
0009                  RETURN
0010                  END
```

```
FORTRAN IV G LEVEL 20.7 VS                GRD2                    DATE =    6/07/77      14:32:
0001                  SUBROUTINE GRD2(A,DX,DZ,PX,PZ,PB,PG,PCOS,PSIN,NP,NS,KE,XO,ZO,ID,
                     1JD)
0002                  COMMON /STORE1/IND(30),INDT(30),NOVIK(30),IS(30)
0003                  DIMENSION A(ID,JD),RM(5),C(5),IC(4),PX(NP,NS),PZ(NP,NS),PG(NP,NS)
                     1PB(NP,NS),PCOS(NP,NS),PSIN(NP,NS),KE(30)
0004                  DO 210 I=1,ID
0005                  DO 210 J=1,JD
0006              210 A(I,J)=0.
0007                  DO 1 N=1,NP
0008                  DO 1 I=1,NS
0009                  PX(N,I)=PX(N,I)+XO
0010                1 PZ(N,I)=PZ(N,I)+ZO
0011                  KX=1
0012                  DO 2 N=1,NP
0013                  KY=KE(N)-1
0014                  IF(KX .GE. KY) GO TO 2
0015                  RM(1)=0.
0016                  C(1)=PZ(N,KX)
0017                  IC(1)=(PX(N,KX)-PB(N,KX))/DX+1.0005
0018                  IC1=PX(N,KX)/DX+1.0005
0019                  IC(2)=(PX(N,KX)+PB(N,KX))/DX+1.0005
0020                  DO 2 K=KX,KY
0021                  PB2S=PB(N,K+1)*PSIN(N,K+1)
0022                  IC(3)=(PX(N,K+1)-PB2S)/DX+1.0005
0023                  IC2=PX(N,K+1)/DX+1.0005
0024                  IC(4)=(PX(N,K+1)+PB2S)/DX+1.0005
0025                  PB2C=PB(N,K+1)*PCOS(N,K+1)
0026                  PB1C=PB(N,K)*PCOS(N,K)
0027                  PB1S=PB(N,K)*PSIN(N,K)
0028                  DZZ=PZ(N,K+1)-PZ(N,K)
0029                  DXX=PX(N,K+1)-PX(N,K)
0030                  DPBC=PB2C-PB1C
0031                  DPBS=PB2S-PB1S
0032                  DS=SQRT(DZZ*DZZ+DXX*DXX)
0033                  CB=PB(N,K+1)-PB(N,K)
0034                  DG=PG(N,K)-PG(N,K+1)
0035                  IF(PSIN(N,K+1) .LT. C.) GO TO 101
0036                  IF(IC(1)-IC(3)) 103,104,105
0037              105 IL=IC(3)+1
0038                  GO TO 112
0039              104 IL=IC(3)+1
0040                  GO TO 113
0041              103 IL=IC(1)+1
0042              112 RM(3)=(DZZ+DPBC)/(DXX-DPBS)
0043                  C(3)=PZ(N,K+1)+PB2C-(PX(N,K+1)-PB2S)*RM(3)
0044              113 DXPB=DXX+DPBS
0045                  IF(DXPB .EQ. 0.) GO TO 20
0046                  RM(4)=(DZZ-DPBC)/DXPB
0047                  C(4)=PZ(N,K+1)-PB2C-(PX(N,K+1)+PB2S)*RM(4)
0048               20 IF(PSIN(N,K+1) .EQ. 0.) GO TO 109
0049                  RM(2)=-PCOS(N,K+1)/PSIN(N,K+1)
0050                  C(2)=PZ(N,K+1)-PX(N,K+1)*RM(2)
0051              109 IR=IC(4)
0052                  IF(IL .GT. IR) GO TO 99
0053                  DO 12 I=IL,IR
0054                  IF(I .GT. ID) GO TO 12
```

```
FORTRAN IV G LEVEL 20.7 VS                GRD2                    DATE =     6/07/77      14:32:

0055                  IF(I .LT. 1) GO TO 12
0056                  X=DX*FLOAT(I-1)
0057                  IF(I .GT. IC(3)) GO TO 7
0058                  ZU=RM(3)*X+C(3)
0059                  GO TO 8
0060                7 ZU=RM(2)*X+C(2)
0061                8 JU=ZU/DZ+1.0001
0062                  IF(I .GT. IC(2)) GO TO 10
0063                  IF(I .GT. IC(1)) GO TO 115
0064                  ZL=RM(3)*X+C(3)
0065                  GO TO 11
0066              115 ZL=RM(1)*X+C(1)
0067                  GO TO 11
0068               10 ZL=RM(4)*X+C(4)
0069               11 IF((ZL-DZ*FLOAT(JU-1)) .GT. 0.) GO TO 12
0070                  JL=ZL/DZ+1.9999
0071                  IF(JU .LT. JL) GO TO 12
0072                  CALL PD2(A,PX,PZ,PB,PG,PCOS,PSIN,RM,C,NP,NS,N,JL,JU,DB,DG,DZ,X,
                     1DXX,DZZ,I,K,ID,JD)
0073               12 CONTINUE
0074                  GO TO 99
0075              101 IF(IC(2)-IC(4)) 121,122,123
0076              122 IL=IC(2)+1
0077                  GO TO 124
0078              123 IL=IC(4)+1
0079                  GO TO 125
0080              121 IL=IC(2)+1
0081              125 RM(4)=(DZZ-DPBC)/(DXX+DPBS)
0082                  C(4)=PZ(N,K+1)-PB2C-(PX(N,K+1)+PB2S)*RM(4)
0083              124 DXDP=DXX-DPBS
0084                  IF(DXDP .EQ. 0.) GO TO 21
0085                  RM(3)=(DZZ+DPBC)/DXDP
0086                  C(3)=PZ(N,K+1)+PB2C-(PX(N,K+1)-PB2S)*RM(3)
0087               21 RM(2)=-PCOS(N,K+1)/PSIN(N,K+1)
0088                  C(2)=PZ(N,K+1)-PX(N,K+1)*RM(2)
0089                  IR=IC(3)
0090                  IF(IL .GT. IR) GO TO 99
0091                  DO 128 I=IL,IR
0092                  IF(I .GT. ID) GO TO 128
0093                  IF(I .LT. 1) GO TO 128
0094                  X=DX*FLOAT(I-1)
0095                  IF(I .GT. IC(1)) GO TO 130
0096                  IF(I .GT. IC(2)) GO TO 132
0097                  ZU=RM(4)*X+C(4)
0098                  GO TO 133
0099              132 ZU=RM(1)*X+C(1)
0100                  GO TO 133
0101              130 ZU=RM(3)*X+C(3)
0102              133 JU=ZU/DZ+1.0001
0103                  IF(I .GT. IC(4)) GO TO 135
0104                  ZL=RM(4)*X+C(4)
0105                  GO TO 136
0106              135 ZL=RM(2)*X+C(2)
0107              136 IF((ZL-DZ*FLOAT(JU-1)) .GT. 0.) GO TO 128
0108                  JL=ZL/DZ+1.9999
0109                  IF(JU .LT. JL) GO TO 128
```

```
FORTRAN IV G LEVEL 20.7 VS              GRD2                DATE =     6/07/77      14:32:

0110                CALL PD2(A,PX,PZ,PB,PG,PCOS,PSIN,RM,C,NP,NS,N,JL,JU,DB,DG,DZ,X,
                   1DXX,DZZ,I,K,ID,JD)
0111              128 CONTINUE
0112               99 RM(1)=RM(2)
0113                  C(1)=C(2)
0114                  IC(1)=IC(3)
0115                  IC(2)=IC(4)
0116                  IC1=IC2
0117                2 CONTINUE
0118                  CH=1.
0119                  IP=1
0120                  IW=20
0121              171 IF(ID .GT. IW) GO TO 172
0122                  IW=ID
0123                  CH=0.
0124              172 WRITE(6,178)
0125              178 FORMAT(1H1)
0126                  DO 662 J=1,JD
0127                  L=JD+1-J
0128              662 WRITE(6,3) (A(I,L),I=IP,IW)
0129                3 FORMAT(1X,20(F5.2,1X))
0130                  IF(CH .EQ. 0.) GO TO 173
0131                  IP=IP+20
0132                  IW=IW+20
0133                  GO TO 171
0134              173 DO 310 N=1,NP
0135                  DO 310 I=1,NS
0136                  PX(N,I)=PX(N,I)-X0
0137              310 PZ(N,I)=PZ(N,I)-Z0
0138                  RETURN
0139                  END
```

```
FORTRAN IV G LEVEL 20.7 VS              PD2                    DATE =     6/07/77      14:32

0001                  SUBROUTINE PD2(A,PX,PZ,PB,PG,PCOS,PSIN,RM,C,NP,NS,N,JL,JU,DB,DG,
                     1DZ,X,DXX,DZZ,I,K,ID,JD)
0002                  DIMENSION A(ID,JD),PX(NP,NS),PZ(NP,NS),PB(NP,NS),PG(NP,NS),
                     1PCOS(NP,NS),PSIN(NP,NS),RM(5),C(5)
0003                  DO 1 J=JL,JU
0004                  IF(J .GT. JD) GO TO 1
0005                  IF(J .LT. 1) GO TO 1
0006                  Z=DZ*FLOAT(J-1)
0007                  PDX=PX(N,K)-PX(N,K+1)
0008                  IF(PDX .NE. 0.) GO TO 5
0009                  XK1=X
0010                  XK=X
0011                  ZK1=RM(2)*XK1+C(2)
0012                  ZK=RM(1)*XK+C(1)
0013                  GO TO 7
0014                5 RM(5)=DZZ/DXX
0015                  C(5)=PZ(N,K+1)-PX(N,K+1)*RM(5)
0016                  CP=Z-X*RM(5)
0017                  IF(PSIN(N,K+1) .EQ. 0.) GO TO 3
0018                  XK1=(C(2)-CP)/(RM(5)-RM(2))
0019                  GO TO 4
0020                3 XK1=PX(N,K+1)
0021                4 ZK1=RM(5)*XK1+CP
0022                7 DXK1=XK1-X
0023                  DZK1=ZK1-Z
0024                  DSB=SQRT(DXK1*DXK1+DZK1*DZK1)
0025                  IF(PSIN(N,K) .EQ. 0.) GO TO 9
0026                  IF(PDX .EQ. 0.) GO TO 10
0027                  XK=(C(1)-CP)/(RM(5)-RM(1))
0028                  GO TO 11
0029                9 XK=PX(N,K)
0030               11 ZK=RM(5)*XK+CP
0031               10 DXK=XK-XK1
0032                  DZK=ZK-ZK1
0033                  DSP=SQRT(DXK*DXK+DZK*DZK)
0034                  RDSBP=DSB/DSP
0035                  XPC=PX(N,K+1)-RDSBP*DXX
0036                  ZPC=PZ(N,K+1)-RDSBP*DZZ
0037                  DXPC=X-XPC
0038                  DZPC=Z-ZPC
0039                  DSC=SQRT(DXPC*DXPC+DZPC*DZPC)
0040                  B=PB(N,K+1)-RDSBP*DB
0041                  AN=(1.-DSC/B)*(PG(N,K+1)+RDSBP*DG)
0042                  IF(AN .GT. A(I,J)) A(I,J)=AN
0043                1 CONTINUE
0044                  RETURN
0045                  END
```

```
FORTRAN IV G LEVEL 20.7 VS              CONTU                   DATE =     8/03/77      10:14:

0001                  SUBROUTINE CONTU(A,B,C,ISET,LIM,NN,IPNT)
0002                  DIMENSION A(ISET,1),B(1),C(1)
0003                  COMMON/CONTUU/WIT,HITE,KEY(4),HEDN(20),
                     * XNIN,XNAX,YNIN,YNAX,XOFF,YOFF,XSIZ ,YSIZ ,NCONT ,IFLAG
0004                  COMMON/LBLCOM/ITEST,SLBL,STTL,SSCL,STICKL
0005                  IF(IPNT.LT.0) GOTO 999
0006                  IF(IPNT.GT.0) GOTO 888
0007                  IF(NN.EQ.0) NN=-10
0008                  NCONT=IABS(NN)
0009                  MAX=MAXO(LIM,ISET)
0010                  DO 2 I=1,LIM
0011                2 CALL MAXMIN(A(1,I),ISET,C(I),C(LIM+I))
0012                  CALL MAXMIN(C,LIM*2,YMAX1,YMIN1)
0013                  CALL SCALE(YMAX1,YMIN1,TOP,BOT,NCONT,IERR)
0014                  IF(IERR.NE.0)  GOTO 1000
0015                  CALL MAXMIN(B,NCONT,BMAX,BMIN)
0016                  IF(BMAX.LT.YMIN1.OR.BMIN.GT.YMAX1) GOTO 4
0017                  IF(NN.GT.0) GOTO 1
0018                4 DELTA=(TOP-BOT)/NCONT
0019                  B(1)=BOT
0020                  DO 3 I=2,NCONT
0021                3 B(I)=B(I-1)+DELTA
0022                1 IF(IFLAG.NE.0) GOTO 6
0023                  ISET1=ISET-1
0024                  LIM1=LIM-1
0025                  YSIZE=HITE
0026                  XSIZE=WIT
0027                  XMIN=1.
0028                  YMIN=1.
0029                  XMAX=ISET
0030                  YMAX=LIM
0031                  YNAX=YMAX
0032                  YNIN=YMIN
0033                  XNAX=XMAX
0034                  XNIN=XMIN
0035                  IF(KEY(2).EQ.1) GOTO 10
0036                  DX=XMAX-XMIN
0037                  DY=YMAX-YMIN
0038                  IF(DX.GT.DY) GOTO 11
0039                  DUM=XSIZE
0040                  XSIZE=YSIZE
0041                  YSIZE=DUM
0042               11 YSIZE=AMIN1(YSIZE,26.)
0043                  DX=AMIN1(XSIZE/DX,YSIZE/DY)
0044                  XSIZE=DX*(XMAX-XMIN)
0045                  YSIZE=DX*(YMAX-YMIN)
0046               10 XBIG=1.3*XSIZE
0047                  IF(XBIG.LT.15.) XBIG=15.
0048                  IF(XBIG.GT.50.) CALL SYSXMX(XBIG)
0049                  YBIG=10.
0050                  IF(YSIZE.LE.10.) GOTO 12
0051                  YBIG=29.
0052                  CALL SYSPSZ(1)
0053               12 YOFF=0.5*IFIX(YBIG-YSIZE)
0054                  XOFF=0.5*IFIX(XBIG-XSIZE)+0.5
0055                  XD=XSIZE/(XMAX-XMIN)
```

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FORTRAN IV G LEVEL 20.7 VS              CONTU              DATE =     8/03/77      10:14

0056                YD=YSIZE/(YMAX-YMIN)
0057                XTOFF=0.1
0058                IF(YSIZE.GT.10.) XTOFF=YSIZE*.01
0059                IF(YSIZE.LT.5..AND.XSIZE.LT.7.5) XTOFF=YSIZE*.02
0060                XTOFF=AMAX1(XTOFF,.05)
0061                ITEST=1
0062                SLBL=1.1*XTOFF
0063                STTL=1.2*XTOFF
0064                SSCL=XTOFF
0065                STICKL=STTL
0066                IF(KEY(4).NE.0) STICKL=0
0067                SYMS=0.8*XTOFF
0068                YT     =YOFF+YSIZE+XTOFF
0069                IF(YT+STTL.GT.YBIG) YT=YOFF+YSIZE-XTOFF-XTOFF-STTL
0070                XSIZ=XSIZE
0071                YSIZ=YSIZE
0072                IF(LIM.GT.ISET) XSIZ=XSIZ*LIM1/ISET1
0073                IF(ISET.GT.LIM) YSIZ=YSIZ*ISET1/LIM1
0074                CALL LABEL(XOFF,YSIZE+YOFF,XMIN,XMAX,XSIZE,-ISET1,' ',-1,0)
0075                CALL LABEL(XSIZE+XOFF,YOFF,YMIN,YMAX,YSIZE,-LIM1 ,' ',-1,1)
0076                CALL FINDMT(HEDN(16),MT16,20)
0077                CALL FINDMT(HEDN(11),MT  ,20)
0078                CALL LABEL(XOFF,YOFF,XMAX,XMIN,XSIZE,-ISET1,HEDN(16),MT16,0)
0079                CALL LABEL(XOFF,YOFF,YMAX,YMIN,YSIZE,-LIM1,HEDN(11),MT,1)
0080                CALL FINDMT(HEDN,MT,40)
0081                IF(MT.EQ.0) GOTO 6
0082                XBEGIN=XOFF+XTOFF
0083                IF(KEY(3).EQ.0)XBEGIN=XOFF+.5*XSIZE+(.1-.4286*MT)*STTL
0084                CALL SYSSYM(XBEGIN    ,YT,STTL,HEDN,MT,0.)
0085              6 IDUM1=1
0086                IDUM2=IDUM1+MAX
0087                IDUM3=IDUM2+MAX
0088                IDUM4=IDUM3+MAX
0089                CALL TOPO(A,B,C(IDUM1),C(IDUM2),C(IDUM3),C(IDUM4),LIM,ISET)
0090                WRITE(6,100)                    (B(I),I=1,NCONT)
0091             100 FORMAT(' ++ CONTU LEVELS ',8G13.5/(1X1P10G13.5))
0092                IFLAG=1
0093                IF(KEY(1).NE.0) RETURN
0094              50 CALL SYSPLT(0.,0.,999)
0095                IFLAG=0
0096                RETURN
0097            1000 WRITE(6,1001) YMIN1,YMAX1,NCONT
0098            1001 FORMAT(' ** TROUBLES **   MIN,MAX,NCONTOUR = ',2G13.5,I5)
0099                RETURN
0100             888 IDUM1=IPNT
0101                DO 88 I=1,ISET
0102                XBIG=XOFF+(B(I)-XMIN)*XD
0103                YBIG=YOFF+(A(I,1)-YMIN)*YD
0104              88 CALL SYSSYM(XBIG,YBIG,SYMS,IDUM1,-1,0)
0105                RETURN
0106             999 XBIG=XOFF+(B(1)-XMIN)*XD
0107                YBIG=YOFF+(A(1,1)-YMIN)*YD
0108                CALL SYSPLT(XBIG,YBIG,3)
0109                IDUM1=MAXO(LIM,1)
0110                DO 99 I=1,ISET,IDUM1
0111                XBIG=XOFF+(B(I)-XMIN)*XD
0112                YBIG=YOFF+(A(I,1)-YMIN)*YD
0113              99 CALL SYSPLT(XBIG,YBIG,2)
0114                RETURN
0115                END
```

```
FORTRAN IV G LEVEL 20.7 VS              BLK DATA          DATE =     8/03/77      10:1

 0001                 BLOCK DATA
 0002                 COMMON/CONTUU/WIT,HITE,KEY(4),HEDN(20),STUFF(9),IFLAG
 0003                 DATA WIT,HITE,KEY,HEDN/8.,8.       ,4*0,20*1H /
 0004                 DATA IFLAG/0/
 0005                 END
```

```
FORTRAN IV G LEVEL 20.7 VS              TOPO                DATE =     8/03/77      10:14

0001                SUBROUTINE TOPO(      V,CNTR,RA,RB,X,Y,M,N)
0002                DIMENSION V(  N ,1),CNTR(1),RA(1),RB(1),X(1),Y(1)
0003                COMMON/CONTUU/SKUPO(26),
                   *                    XMIN,XMAX,YMIN,YMAX,XOFF,YOFF,XSIZ ,YSIZ ,NCONT
0004                 SX=XMAX-XMIN
0005                 SY=YMAX-YMIN
0006                SMAX=AMAX1(SX,SY)
0007                SMAX1=1./SMAX
0008                 SS=SX*SMAX1
0009                SYS=SY*SMAX1
0010                SSS=0.5*SYS
0011                Y1 = SY*SMAX1- .001
0012                X2 = SX*SMAX1- .001
0013                YCONV=SMAX1
0014                 DELTAX=N-1
0015                 DELTAX=(XMAX-XMIN)/DELTAX
0016                 X(1) = 0.
0017                RB(1) = V(1,1)
0018                DO 27 J=2,N
0019                 RB(J)=V(J,1)
0020             27  X(J)=X(J-1)+DELTAX
0021                 DELTAY=N-1
0022                 DELTAY=(YMAX-YMIN)/DELTAY
0023                 Y(1) = 0.
0024                DO 28 J=2,M
0025             28  Y(J)=Y(J-1)+DELTAY
0026                DO 118  K=2,M
0027                 DO 30 J=1,N
0028                 RA(J)=RB(J)
0029             30 RB (J)=V(J,K)
0030                DO 118  J=2,N
0031             35 ASSIGN 112 TO L
0032                RR=RA(J)
0033                XX=X(J)
0034                YY=Y(K-1)
0035             37 RL=RR
0036                XL=XX
0037                YL=YY
0038             39 IF(RL.LT.RA(J-1)) GOTO 41
0039             40 IF(RL-RB(J))42,50 ,50
0040             41 RL=RA(J-1)
0041                XL=X (J-1)
0042                YL= Y(K-1)
0043                GO TO 40
0044             42 RL=RB(J)
0045                XL=X (J)
0046                YL=Y(K)
0047             50 RS=RR
0048                XS=XX
0049                YS=YY
0050                IF(RS.GT.RA(J-1)) GOTO 53
0051             52 IF(RS-RB(J)) 60,60,54
0052             53 RS=RA(J-1)
0053                XS=X (J-1)
0054                YS =Y(K-1)
0055                GO TO 52
```

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FORTRAN IV G LEVEL 20.7 VS              TOPO                DATE =     8/03/77      10:14:

0056            54 RS=RB(J)
0057               XS=X (J)
0058               YS=Y (K)
0059            60 RM=RR
0060               XM=XX
0061               YM=YY
0062                IF (RM-RS) 62,2062,61
0063          2062  IF (XM.EQ.XS .AND. YM.EQ.YS) GO TO 62
0064            61  IF (RM-RL) 70,2065,62
0065          2065  IF(XM.EQ.XL .AND. YM.EQ.YL) GO TO 62
0066                GO TO 70
0067            62 RM=RA(J-1)
0068               XM=X (J-1)
0069               YM=Y (K-1)
0070                IF (RM-RS) 64,2063,63
0071          2063  IF (XM.EQ.XS .AND.YM.EQ.YS) GO TO 64
0072            63  IF (RM-RL) 70,2064,64
0073          2064  IF (XM.EQ.XL .AND. YM.EQ.YL) GO TO 64
0074                GO TO 70
0075            64 RM = RB(J)
0076               XM=X (J)
0077               YM=Y (K)
0078            70 YCS=YS*YCONV
0079               YCM=YM*YCONV
0080               YCL=YL*YCONV
0081            71 YS=YS-YMAX+YMIN
0082               YM=YM-YMAX+YMIN
0083               YL=YL-YMAX+YMIN
0084            72  XCS=XS*SMAX1
0085                XCM=XM*SMAX1
0086                XCL=XL*SMAX1
0087               NC=1
0088               RC=CNTR(1)
0089            80 IF(NC.GT.NCONT) GOTO110
0090               IF ( RC .NE. RM ) GO TO 91
0091            81 IF ( RM .NE. RS ) GO TO 91
0092            82 IF ( RL .EQ. RM ) GO TO 100
0093            91 IF(RC.LT.RS) GOTO 100
0094               IF(RC-RM)96,93,94
0095            93 XPA=XCM
0096               YPA=YCM
0097               GO TO 99
0098            94 IF(RC-RL)106,103,110
0099            96 Q = (RC-RS)/(RM-RS)
0100            97 XPA = XCS-Q*(XCS-XCM)
0101               YPA = YCS-Q*(YCS-YCM)
0102            99 Q = (RC-RS)/(RL-RS)
0103               XPB = XCS-Q*(XCS-XCL)
0104               YPB = YCS-Q*(YCS-YCL)
0105               IF(RC)10115,10116,10116
0106        10115 XPB1=0.5*(XPA+XPB)
0107               YPB1=0.5*(YPA+YPB)
0108               IF(ABS (XPA-XPB1)-.001)5001,5002,5002
0109          5001 IF(ABS (YPA-YPB1)-.001)100,5002,5002
0110          5002 CALL PLOTZ(XPA,YPA,XPB1,YPB1)
0111               GO TO 100
```

```
FORTRAN IV G LEVEL 20.7 VS                TOPO                    DATE =     8/03/77      10:14

0112          10116 IF(ABS (XPA-XPB)-.001)5003,5004,5004
0113           5003 IF(ABS (YPA-YPB)-.001)100,5004,5004
0114           5004 CALL    PLOTZ(XPA,YPA,XPB,YPB)
0115            100 RC=CNTR(NC+1)
0116                NC=NC+1
0117                GO TO 80
0118            103 XPA = XCL
0119                YPA = YCL
0120                GO TO 99
0121            106 Q=(RC-RM)/(RL-RM)
0122                XPA=XCM-Q*(XCM-XCL)
0123                YPA=YCM-Q*(YCM-YCL)
0124                GO TO 99
0125            110  GO TO L,(112,118)
0126            112  ASSIGN 118 TO L
0127                RR    =RB(J-1)
0128                XX    =X (J-1)
0129                YY    =Y (K)
0130                GO TO 37
0131            118 CONTINUE
0132                 RETURN
0133                 END
```

```
FORTRAN IV G LEVEL 20.7 VS                    PLOTZ                    DATE =     8/03/77      10:14:
0001                  SUBROUTINE PLOTZ(X1,Y1,X2,Y2)
0002                  INTEGER EC
0003                  LOGICAL*1 LXS
0004                  DIMENSION X(2),Y(2),LXS(1)
0005                  COMMON/CONTUU/SKIUP(26),
                     *             XMIN,XMAX,YMIN,YMAX,XOFF,YOFF,XSIZE,YSIZE,NCONT
0006                  X(1)=XSIZE *X1+XOFF
0007                  X(2)=XSIZE *X2+XOFF
0008                  Y(1)=YSIZE *Y1+YOFF
0009                  Y(2)=YSIZE *Y2+YOFF
0010                  CALL SYSPLT(X(1),Y(1),3)
0011                  CALL SYSPLT(X(2),Y(2),2)
0012                  RETURN
0013                  ENTRY FINDMT(LXS,MT,NBT)
0014                  MT=NBT
0015                  DO 44 J=1,NBT
0016                  IF(EC(LXS(MT),' ').EQ.0) RETURN
0017               44 MT=MT-1
0018                  RETURN
0019                  END
```

```
FDYN     SUPPORT FOR FORTRAN DYNAMIC BIT AND FULLWORD ARRAYS.                                                
```

```
 LOC   OBJECT CODE     ADDR1 ADDR2  STMT   SOURCE STATEMENT

000070 98E4 D00C       0000C        54+          LM    14,4,12(13)                RESTORE THE REGISTERS   00260000
000074 92FF D00C       0000C        55+          MVI   12(13),X'FF'               SET RETURN INDICATION   00640000
000078 41F0 0000       00000        56+          LA    15,0(0,0)                  LOAD RETURN CODE        00700000
00007C 07FE                         57+          BR    14                         RETURN                  00800000
000000                              58 ANCHOR    DSECT                                                    465
000000                              59           DS    F                          UNUSED WORD.            469
000004                              60 DIMEN     DS    F                          BITS/ROW OR # OF FULLWORDS. 470
000008                       00000  61           ORG   ANCHOR                                              475
000000                              62 LENGTH    DS    2F                         LENGTH OF THE ARRAY, BYTES. 476
000008                              63 INCR      DS    F                          BYTES BETWEEN ROWS IN A BIT  * 480
                                                                                  ARRAY.                       481
                             00008  64 INDEX     EQU   INCR                       INDEX FROM START OF ANCHOR TO * 482
                                                                                  START OF ARRAY FOR FULLWORD  * 483
                                                                                  ARRAYS.                      484
                                    65           END                                                      486
```